A PROJECT REPORT

ON

LIM: AN APPROACH TO INCREASE LEVERAGE OF HANDPUMPS USING EXTERNAL MOUNTING

In partial fulfilment for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

MECHANICAL & AUTOMATION ENGINEERING

Submitted by

Tridib Banerjee	**A20405414071**
Veer Singh Shekhawat	**A22205414016**

Under guidance of

Mr. Pankaj Agarwal
Assistant Professor, Dept of Mechanical Engineering

MAY 2018

DEPARTMENT OF MECHANICAL AND AUTOMATION ENGINEERING

AMITY UNIVERSITY RAJASTHAN

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Amity School of Engineering & Technology

DECLARATION

I hereby declare that this submission is my own work and to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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CERTIFICATE

I hereby certify that the work which is being presented in the B.Tech. Major (or Minor) Project Report entitled **“***LIM: An Approach To Increase Leverage Of Handpumps Using External Mounting”,* in partial fulfilment of the requirements for the award of the **Bachelor of Technology in Mechanical & Automation Engineering** and submitted to the Department of Mechanical & Automation Engineering of *Amity School of Engineering and Technology, Amity University Rajasthan* is an authentic record of my own work carried out during a period from January 2018 to May 2018 under the supervision of Mr. Pankaj Agarwal, Assistant Professor, Dept of Mechanical Engineering. The matter presented in this thesis has not been submitted by me for the award of any other degree elsewhere.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date:

Signature of Internal Supervisor(s)
Mr. Pankaj Agarwal, Assistant Professor, Dept of Mechanical Engineering

ACKNOWLEDGEMENT

This project is the cumulation of not just our efforts but also guidance and support from various people throughout a varied range of domains. To begin with, we would like to acknowledge the truly continuous support that our **Guide, Mr. Pankaj Agarwal**, has bestowed upon us. Be it for brainstorming a solution or getting our transport vehicle a pass to the university, be it in working hours or in off-days, he has made himself reachable to us throughout this four-month long endeavour and for this we shall always remain indebted to him. Every sector of our project has his contribution and our project would never have seen the light of the day had it not been for him. Dear sir, we sincerely express our gratitude to you. We also express our gratitude to our **HOD, Mr. Mangal Singh Sisodia**, and our **Director, Dr. D.D. Shukla** for making the department's resources available to us always.

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ABSTRACT

In this project a new mounting is proposed which can be externally mounted on handpumps such that it increases its mechanical leverage. It is estimated that if we succeed, this invention will at the very least, effect the lives of more than 570 million people in India alone for good. It was designed keeping in mind easy fabrication, and cheap production such that it can be implemented on the widest scale possible in an economically tight country such as India. A four-bar linkage-based rocker bar mechanism was proposed for it. Aluminium alloy 1350 was proposed as the optimum material. Its motion was studied in detail. Kinematic, dynamic and ergonomic constraints were proposed. The mechanism was found to increase the leverage by 74.8% and the number of oscillations of the main lever by 3 times. This resulted to a total potential of 8 times more water compared to a generic handpump. The mechanism was prototyped using a mild steel-based setup. Based on experimentation, three new correction factors were introduced, K_d(deflection factor), K_c(effective contact surface factor) and K_l (effective leverage length factor). Finally, it was found that after considering a worst-case scenario of dynamic cyclic loading continuously for more than 10^6 cycles, the factor of safety (FOS) was still found to be 1.81. The project was therefore considered a success.

KEYWORDS

Leverage inducing mounting, reciprocating pumps, handpumps, kinematic analysis, dynamic analysis, kinematic constraints, ergonomic constraints, four bar mechanism, increase in efficiency, increase in mechanical leverage, effective leverage length factor, effective surface contact factor, deflection factor, plunging force.

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LIST OF SYMBOLS & ABBREVIATIONS

Symbol	Function
$F_{applied}$	The net applied force
F_t	The tangential force generated at the driving disc
F_l	The net force being transmitted through the coupler
F_{eq}	The net equivalent force that is responsible for the output moment of the lever
Θ	The angle between F_{eq} and F_l
α	The angle between F_t and F_l
$\emptyset$	The angular displacement of the lever about the hinge point
l_1	The distance between $F_{applied}$ and center of the driving gear
l_2	The distance between F_{eq} and hinge point
h_2	The length of the main coupler
D_1	The diameter of the driving gear
D_2	The diameter of the driven gear
D_3	The diameter of the driving disc
τ_{fin}	The final torque obtained
MA	The mechanical advantage
F_p	The obtained plunging force
F_{pc}	The conventional plunging force
FOS	The factor of safety
K_d	The deflection factor
K_c	The effective contact surface factor
K_l	The effective leverage length factor

CHAPTER 1: INITIAL STUDY

A. INTRODUCTION

According to India Water Portal [1], 26% of urban population and more than 50% of rural population in India depends on reciprocating pumps as their primary source of water. The number has increased by more than 3% in the last decade. We know that the most common reciprocating pumps are handpumps (deep and extra deep type), working on either push, pull or suction mechanism. These handpumps are extremely inconvenient. They have low efficiency and causes extreme fatigue in the user. It is therefore surprising that much research has not been done on it.

According to worldometer [2], one of the leading statistical compiling sites that compiles data from more than hundreds of reputable sources like United Nations Statistics Division, World Bank, UNESCO Institute for Statistics, etc, the current population of India is 1,354,051,854 or 1.354 billion people [table A.1] with an urban population density of 32.5 %. Therefore, if we succeed, conservative estimates show that we will be able to improve the lives of more than 42% (42.2% to be exact) of India’s total population. That equates to lives of more than 570 million people (571,409,883 to be exact). We cannot even imagine what a large-scale impact that will be. Therefore, it is undoubtedly of paramount importance, especially in a country like India, which is heavily dependent on reciprocating pumps, to survey all the improvements that have been achieved and come forth with our own improvement that can further better the lives of so many people.

Year	Population	Density (P/Km²)	Urban Pop %	Urban Population	Country's Share of World Pop	India Global Rank
2018	1,354,051,854	455	32.5 %	449,945,237	17.74 %	2
2017	1,339,180,127	450	32.8 %	439,801,466	17.74 %	2
2016	1,324,171,354	445	32.5 %	429,802,441	17.73 %	2
2015	1,309,053,980	440	32.1 %	419,938,867	17.73 %	2

TABLE A.1: *Population of India*

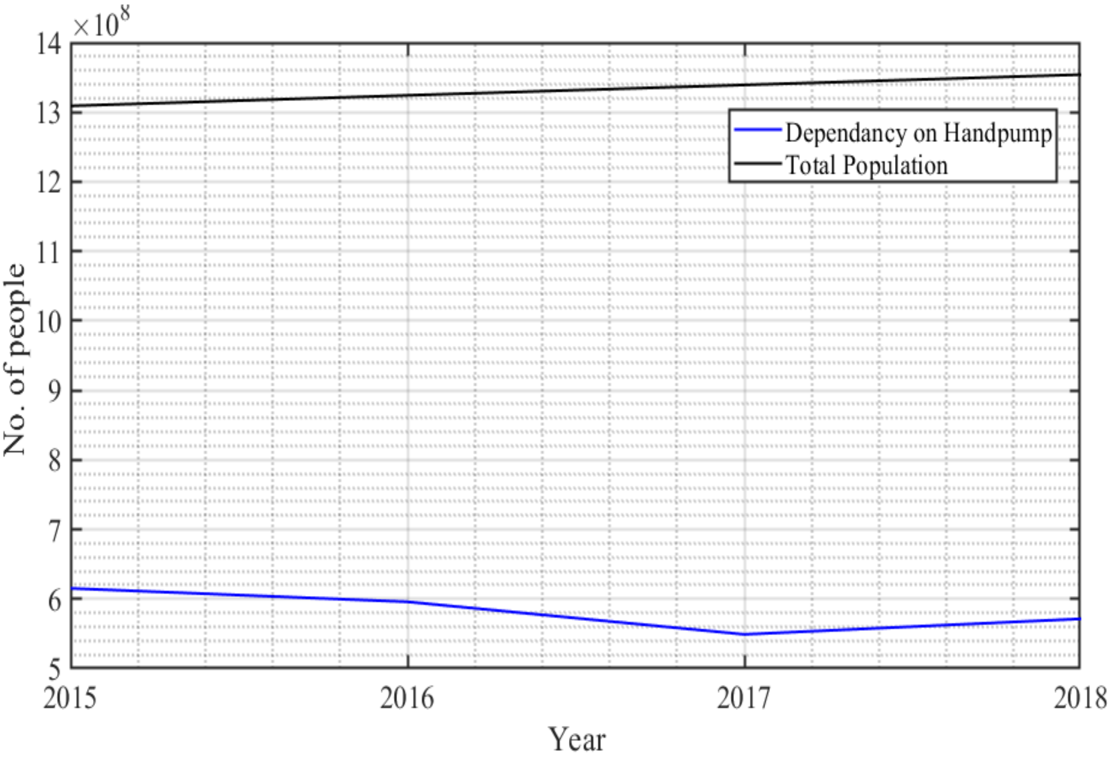

FIGURE A.1: *India's total population & no. of people dependent on* reciprocating pumps.

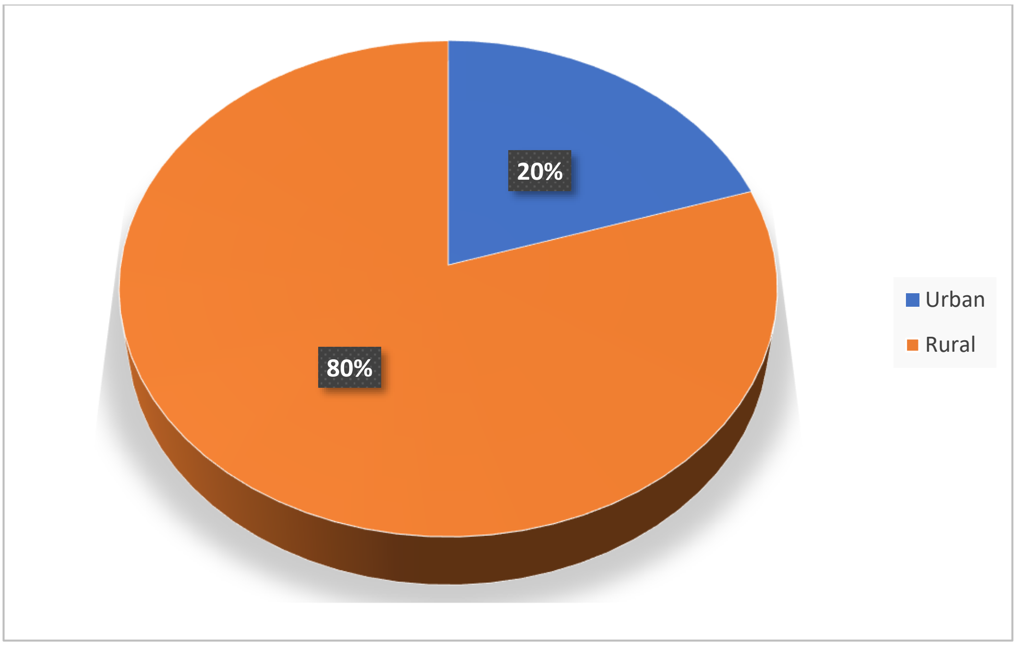

FIGURE A.2: *Composition of the population that is depended on* reciprocating pumps.

B. LITERATURE REVIEW

Before we can begin, we must first survey with scrutiny as to what has been done till date, regarding improvement of reciprocating pumps. The first proper analysis was done by Fei et al [3]. They reported that India Mark II pump is easy to manufacture. Its primary feature was cast iron pump cylinder and stainless steel 48-mm diameter riser pipe that eliminated the problem of corrosion. They further reported that the pump was very difficult to maintain, because with any little problem in the pumping mechanism, the riser pipes must be removed, and this may result in the community remaining without water over a long period. This led to the development of other models: the live Niger pump Model Marks-2, India Mark III hand pump, UNICEF No.6 hand pump and the power hand pump, all from India. UNICEF lead by Okon [4] proposed incorporating a spring valve to increase the leakage efficiency.

Tsui and Lu [5] evaluated the performance of a valve-less-micropump by CFD. They also carried out lumped system analysis. In multidimensional simulation of CFD model, Navier-Strokes equation has been solved by using finite volume method. They only considered half part of pump for calculation due to symmetrical geometry. In lumped system, pumping process was divided into three mode such as pump mode, supply mode and transition mode. In pump mode, the fluid emerges from the chamber due to the high chamber pressure. In supply mode, the fluid is forced to flow into the chamber. In transition mode, the fluid outside the outlet flows into the chamber and the fluid inside the chamber flows out through the intake element. The plots of streamlines and pressure contours in nozzle/diffuser regions have been studied. The result indicates that at 2000 Pa back pressure simulation, pump mode and supply mode efficiency was 4%, 9% and 15% respectively.

Kumar and Bergada [6] studied the effect of piston grooves performance in an axial piston pumps via CFD analysis. In this study, Reynolds equation of lubrication in Cartesian coordinate has been applied to the piston cylinder clearance. This equation also considers the piston eccentricity and the relative tangential movement between piston and barrel. Different grooves configurations have been studied. The result indicates that grooves placed towards the inner edge of the piston produces 1.5% higher force on piston surface with respect to the non-grooved piston.

Fan et al [7] studied computational fluid dynamic analysis and design optimization of jet pumps. The compressible flow within the jet pump has been modelled using Navier-Stokes equation. In this study, the standard k−ε turbulence model has been used. The comparison between analytical and CFD prediction of Mach number have been studied. The CFD prediction of pump efficiency for original and optimized designs at a range of entrained flow rates ranging from 0 L/min to 200 L/min has been studied. The result indicates that the pump efficiency increases from 29 % to 33 %. The energy requirement of the pump is reduced by 20%.

Alves et al [8] studied analytical and CFD modelling of the fluid flow in an eccentric tube centrifugal oil pump for hermetic compressors. In CFD modelling, the fluid flow in eccentric tube oil pumping system has been solved numerically using FLUENT package. The analytical model for the pick-up tube and shaft channel were developed independently and were coupled via a numerical procedure to determine the steady state volume flow rate assembly. The steady state results have been verified against a CFD model. The contours of volume oil fraction as a function of time has been studied. The result indicates that the maximum flow rate was observed for an inclination angle of 68°.

Luckmann et al [9] studied the analysis of oil pumping in a reciprocating pump. In this study, CFD analysis of the oil pumping system of a reciprocating compressor has been done. The commercial CFD package Fluent has been used and the two-phase free surface gas-liquid flow has been resolved through the volume of fluid method. The calculated oil flow rate has been compared with an experimental datum. Results show in terms of phase fraction contours representing the volumetric flow rate of the oil as a function of time. It is observed that the climbing time is of the order of 0.6 s.

Kumar et al. [10] studied analysis of axial piston pump grooved slipper by CFD simulation. In this study, static and dynamic characteristics of a piston pump slipper with groove were investigated. Three dimensional Navier Stokes equations in cylindrical coordinates have been applied to the slipper gap, including the groove. Fluid momentum interchange inside the groove has been studied. Vorticity inside the groove has been analysed under several working conditions. A test rig has been built to compare experimental and CFD results. The result indicates that the slipper leakage at 10 MPa inlet pressure for 17 microns true clearance is 0.10 l/min and 17 microns CFD clearance is 0.082 l/min.

Pei et al. [11] studied collision characteristics for reciprocating pump using FEA and experimental. In this study, the valve disc motion parameters have been measured directly by displacement and acceleration sensor, where both are mounted on the valve disc. The test data has been used as valve motion parameters to simulate the collision process by ANSYS/LS-DYNA software. Valve disc vibration displacement and velocity signal has been studied for different strokes. The simulation and experimental results have been used for studying pump valve failure mechanism, optimization of design and then improving pump services life. Approximation theory has 2.12% less displacement of valve disc as compare to U.Adolph theory for stroke of 200(times/min).

Kumar et al. [12] studied optimization of connecting rod parameter using CAE tools. The model has been developed in Pro/E wildfire 5.0 and then imported in ANASYS workbench. In this study, only static FEA of connecting rod has been performed. During analysis two cases have been analysed one with load applied at the crank end and restrained at the piston end, and the other with load applied at the piston end and restrained at the crank end. The analysis has been carried out under the axial and buckling loads. The result indicated that the weight of the connecting rod was reduced by 0.004 Kg. The percentage reduction of weight was 3.05 %.

Parkash et al. [13] studied optimization of design of connecting rod under static and fatigue loading. In this study, the mathematical model of connecting rod has been developed. The model of connecting rod was developed in CATIA. During analysis two cases analysed, one with load applied at the crank end and restrained at the piston end, and the other with load applied at piston end and restrained at the crank end. The comparisons for static and fatigue loading have been studied under same boundary condition. The result indicated that the weight of connecting rod was reduced by 0.005 Kg. The percentage reduction of weight was 0.23 %.

Singh and Nataraj [14] studied the performance of plunger pump at various crank angles using CFD. The triplex plunger pump has been used for analysis. Due to the complexity of analyzing triple cylinder pump, single cylinder domain has been extracted. The extracted model has been subdivided into number of smaller parts and converted it into non-dimensional coordinates for grid generation. In his investigation the effect of volume flow rate considering the turbulence model as standard K- ε model. The maximum flow rate was observed at crank angle of 300°. The volumetric efficiency of the pump using CFD was found to be 91% and slip 8.98%.

Samad and Nizamuddin [15] studied flow analysis inside jet pump used for oil wells. In this study, Reynold-averaged Navier Stokes (RANS) equation has been solved. The turbulence k-ε model has been used for simulation. The numerical study has been performed for different primary and secondary fluids. The effect of the area ratio and the throat length on the performance of the jet pump has been studied. The result indicated that the efficiency of the jet pump increased up to 20% to 30%.

Hubacher and Groll [16] studied crankshaft bearing analysis of a single stage, Semi-Hermetic Carbon Dioxide compressor. In this study, the friction loss analysis has been conducted, which was used previously obtained compressed performance data as inputs. In the first step, the force loads acting on the two-crankshaft bearing have been predicted based on the operating conditions. In the next step, the predicted force loads have been used in the bearing loss analysis. The result indicated that the frictional losses of the two crankshaft bearings contribute with approximately 19 to 43% to the total frictional losses.

Deng et al. [17] carried out analysis of oil discharge rate in rotary compressor by using CFD. The lubricant oil plays an important role in a hermetic compressor. It provides lubrication to the part and fills in the sealed parts to reduce gas leakage. Also, it removes heat generated from mechanical friction of sliding parts. The flow field of rotary compressor has been calculated by Volume of fluid method. The turbulent K- Epsilon model has been used. Oil pumping height for different scheme has been studied. The result indicates that the maximum oil circulation ratio is 2.85%. Oil circulation ratio is used to denote oil discharge rate of rotary compressor.

Diany and Bouzid [18] evaluated the stresses and displacement of stuffing box packing based on a flexibility analysis. An analytical model based on thick cylinder theory has been developed to model stem-packing-housing interaction. The model gave reliable contact pressure distributions at the interfaces and predicted the deformation involved. The model suggested that the contact pressure ratio was close to one. The interface contact pressure depends on several parameters including geometry, material and friction. The model has potential in predicting contact stress as a function of geometry, material and friction coefficient. The result indicated that for the same axial stress the friction coefficient was less than the 10%.

A very comprehensive review of improvements to pump was done by Thorat et al, which can be found in [19].]. In 1998, Eller et al acquired a patent for pedal based pump [20]. Lastly, Nasir et al [21] in 2004, proposed a gear train based pump. They reported the discharge rates for pump with a gear drive to be almost double than pump without a gear drive for all the recorded number of strokes. The implication of the results was that with an increase in the suction no extra effort was required to discharge at the usual rate. As we can see, no one tried to approach it from a mounting point of view, which is what we hope to achieve.

C. RECIPROCATING PUMPS

Pumps are the hydraulic machines which convert the mechanical energy into hydraulic energy which is mainly in the form of pressure energy. If the mechanical energy is converted into hydraulic energy, by means of centrifugal force acting on the liquid, the pump is known as centrifugal pump. But if the mechanical energy is converted into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards), that exerts the thrust on the liquid and increases its hydraulic energy (pressure energy), the pump is known as Reciprocating pump. Although reciprocating pumps have been around for over 2000 years, they did not gain wide popularity until 1840 when Henry R. Worthington invented the steam pump. These early, simple machines have evolved into the advanced reciprocating products seen today in many industries. During the last 30 years technology improvements have allowed centrifugal and other pump types to become more popular, and reciprocating machines have become somewhat marginalized. That being said, there are still many applications where reciprocating pumps outperform their centrifugal counterparts. The dominance of these alternative pump types has led to a knowledge gap for positive displacement machines. However, the positive displacement reciprocating pump is still a vital part of industry and will remain in use for the foreseeable future.

By definition, a reciprocating pump is any machine using reciprocating motion to cause fluid to be moved from one location to another. The most common form of reciprocating pump is the positive displacement type. This type of pump traps a fixed volume (Figure A.1) of fluid and displaces it from suction conditions to discharge conditions by means of check valves placed in series, at least one on the suction side and at least one on the discharge side. These check valves ensure fluid movement is in one direction from pump suction toward the pump discharge. Since a fixed volume of fluid is displaced the rate of flow is directly proportional to speed. Capacity can also be increased by using a pump with multiple plungers or pistons.

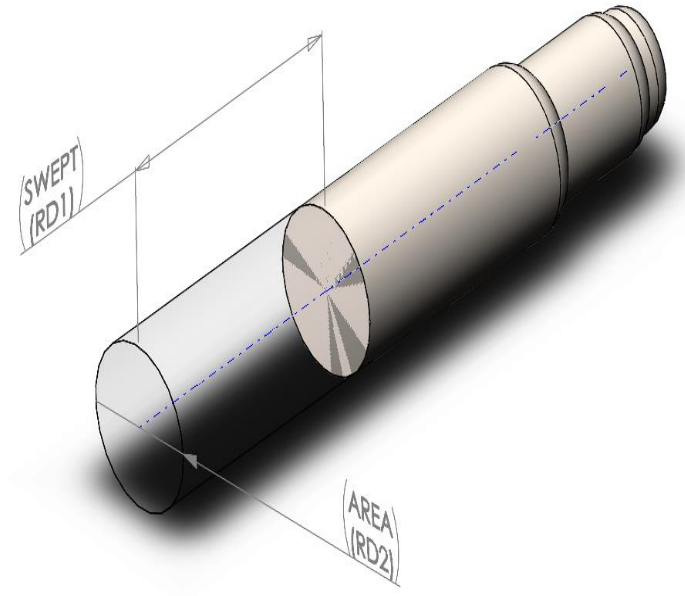

FIGURE C.1: *Fixed Displaced Volume*

As a result of the fixed displaced volume per pump revolution and the fact that pressure is independent of pump speed and flow rate, there is no capacity-head curve for these machines as with centrifugal pumps. If a capacity curve were to be drawn, it would simply be a straight line from zero capacity and speed to maximum capacity and speed like shown in Figure A.2 at 100 percent (theoretical) volumetric efficiency and another line at actual application volumetric efficiency.

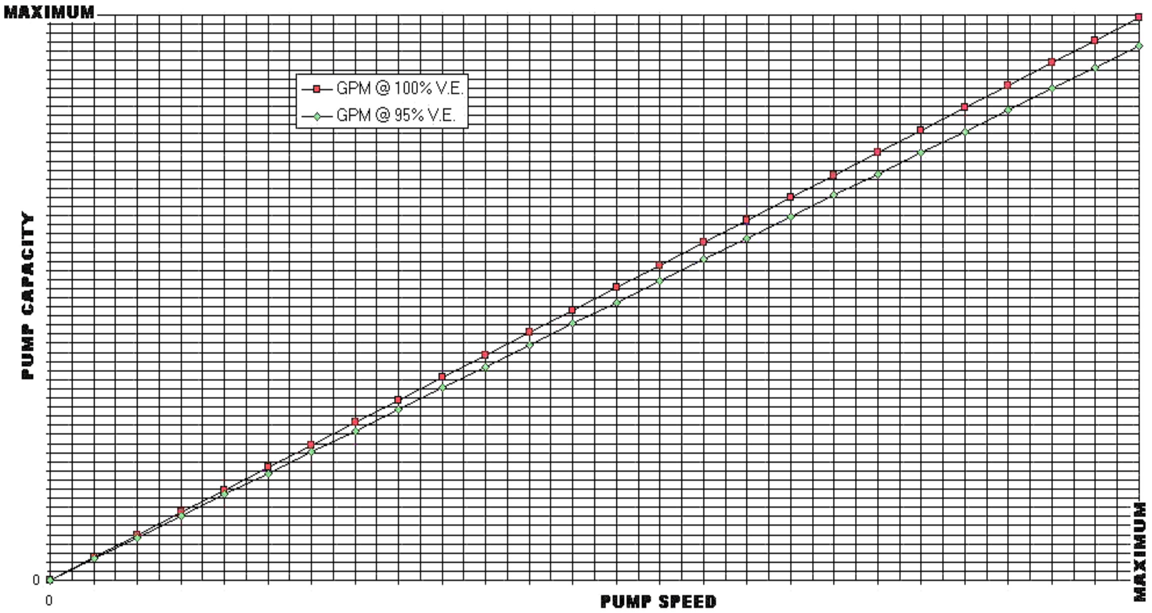

FIGURE C.2: *Fixed Displaced Volume Capacity Curve*

Reciprocating pump and all its differences has been explored to great details by Herbert H. Tackett, Jr. et al, in their wonderful publication [22].

D. HAND PUMPS

A hand pump is a special type of reciprocating pump. In its barebones, it is essentially a lever coupled with a plunger that reciprocates. Given below (Figure D.1) is a detailed diagram for it courtesy of Shafer, Emerson Process management. The majority of people in the developing world gain access to groundwater either by means of a bucket and rope, or by using a handpump. Using a bucket and rope can be made easier if the well is provided with a windlass to help lift the bucket.

However, although easy to operate and repair, the bucket and windlass arrangement has serious disadvantages: it does not allow the well to have a sealable cover slab to prevent ingress of polluted water or other contaminants, and the bucket and rope themselves are continually polluted by mud and dirty hands. Therefore, if the water to be raised from a well or borehole is for people to drink, it is preferable to install a handpump.

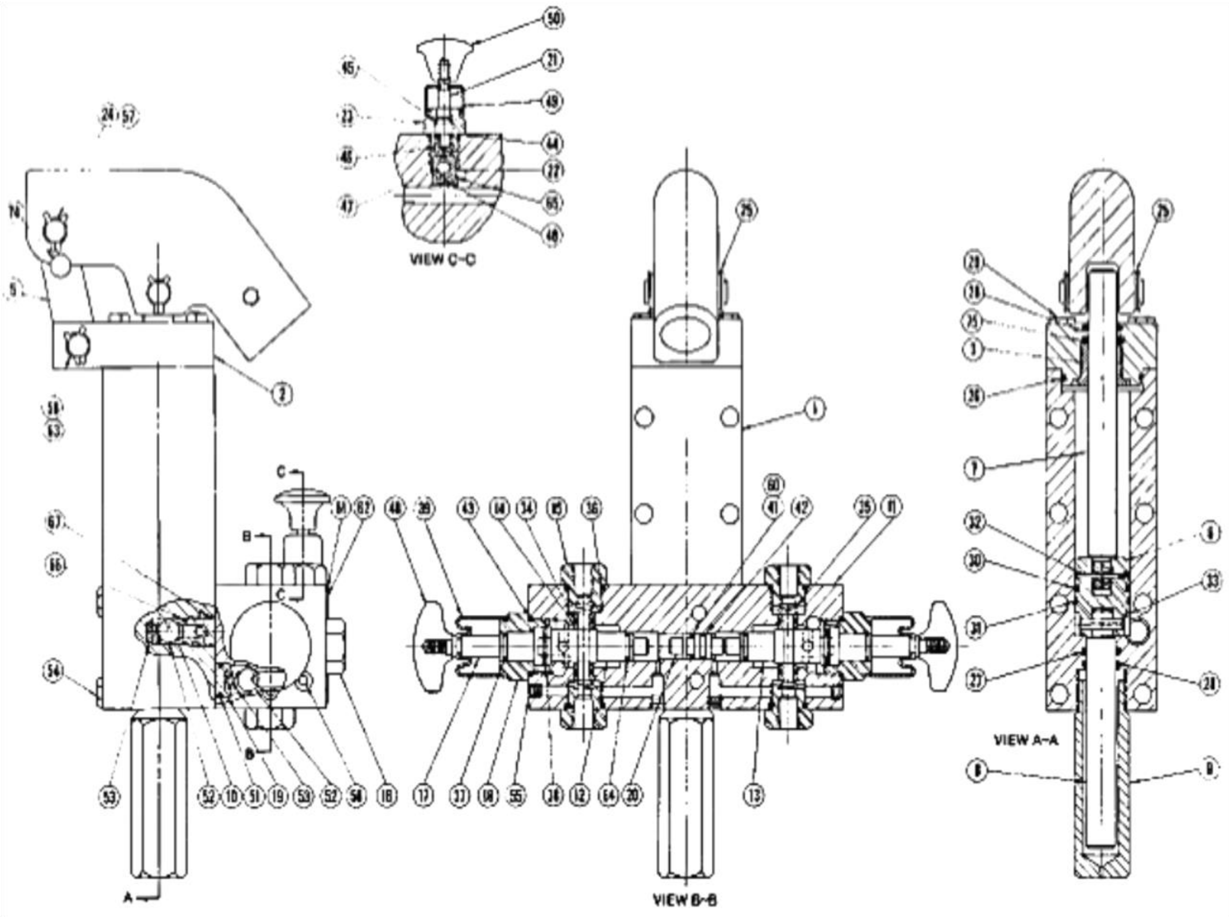

FIGURE D.1: *A detailed layout of Gas Hydraulic Hand Pump*

1. Pump Body
2. 1 Pump Head
3. 1 Packing Gland
4. 1 Clevis
5. 1 Pivot Bar
6. 1 Pump Piston
7. 1 Top Ram
8. 1 Bottom Ram
9. 1 Ram Protective Cover
10. 1 Pump Suction Seat
11. 1 Valve Body
12. 1 Left Valve Sleeve
13. 1 Right Valve Sleeve
14. 6 Ring Seal
15. 4 Ring Seal Cap
16. 2 Valve Cap

17. 2 Stem
18. 2 Stem Cap
19. 2 Suction Cap
20. 1 Pilot Piston
21. 1 Relief Stem
22. 1 Relief Seat
23. 1 Relief Cap
24. 2 Clevis Pin S.S.
25. 4 Acetal Bearing
26. 1 Pump Head O-Ring Comp.479-70 70 Duro
27. 1 Ram O-Ring Comp.479-70 70 Duro
28. 2 Ram Wiper 90 Duro
29. 4 Head Bolt Hex Head Cap Screw S.S.
30. 1 Piston O-Ring Comp.479-70 70 Duro
31. 2 Piston Guide Ring
32. 1 Top Ram Spring Pin
33. 1 Bottom Ram Spring Pin
34. 6 O-Ring Comp.479-70 70 Duro
35. 6 Ring Seal Spring
36. 6 Ring Seal Cap Comp.479-70 70 Duro
37. 2 O-Ring Comp.479-70 70 Duro
38. 2 Stem Spring Pin
39. 2 Stem Boot
40. 2 Stem Knob
41. 1 Pilot Piston O-Ring Comp.479-70 70 Duro
42. 1 Pilot Piston Guide Ring
43. 2 Stem Cap O-Ring Comp.479-70 70 Duro
44. 1 Relief Cap O-Ring Comp.479-70 70 Duro
45. 1 Relief Stem O-Ring Comp.479-70 70 Duro
46. 2 Relief Stem Spring
47. 1 Relief Ball Nylon
48. 1 Relief Spring
49. 1 Relief Boot
50. 1 Relief Knob
51. 1 O-Ring Comp.479-70 70 Duro
52. 4 Nylon Ball
53. 3 Suction & Discharge Spring
54. 4 Valve Bolts Hex Head Cap Screw S.S.
55. 2 Flush Plug (STL) 7/8 Taper
56. 9 Flush Plug (STL) 7/8 Taper
57. 6 "X" Washer
58. 2 Acetal Bearing
59. 1 Flush Plug 7/8 Taper Steel
60. 2 Pilot Piston Back-Up Ring
61. 1 Instruction Plate
62. 4 Instruction Plate Screws #4 Type "U"
63. 1 Clevis Pin S.S.
64. 2 O-Ring Comp.479-70 70 Duro
65. 1 O-Ring Comp.479-70 70 Duro
66. 1 O-Ring Comp.479-70 70 Duro
67. 1 O-Ring Comp.479-70 70 Duro
68. 1 O-Ring Comp.479-70 70 Duro
69. 1 O-Ring Comp.479-70 70 Duro
70. 1 Flush Plug 7/8 Taper Steel
71. 1 Locking Pin
72. 1 Upper Ram Seal
73. 1 Rod Seal

There are many different types of handpump. However, most of them are positive displacement pumps and have reciprocating pistons or plungers. In a piston pump, the piston is fitted with a non-return valve (the piston valve) and slides vertically up and down within a cylinder that is also fitted with a non-return valve (the foot valve). Raising and lowering the handle of the pump causes vertical movement of pump rods that are connected to the piston. When the piston moves upwards, the piston valve closes, and a vacuum is created below it, causing water to be drawn into the cylinder through the foot valve, which opens. Simultaneously, water above the piston, held up by the closed piston valve, is displaced upwards. In a simple suction pump, it emerges through the delivery outlet; in a pump with a submerged cylinder it is forced up the rising main.

When the piston moves downwards, the foot valve closes, preventing backflow, and the piston valve opens, allowing the piston to move down through the water in the cylinder. Given below is a simplified schematic diagram.

The recommendations for handpumps that are proposed for use in community-based water supply projects have been set out clearly in the World Bank/UNDP Handpumps Project [23] As well as the manufacture and performance specifications, the VLOM principles outline many attributes relating to ease of maintenance, local manufacture, robustness, standardisation, low capital cost and operating costs, availability of spares, and community management and maintenance.

When considering the most appropriate pump for a particular project, it is also important to take into account local preferences and government policy. Pumps and their spares should be freely available in local markets as a pre-requisite for ease of maintenance and replacement. Imported or donated pumps that are not available in the local markets are therefore considered inappropriate.

CHAPTER 2: MECHANISM

E. FOUR – BAR LINKAGE

After going through multiple mechanisms, the Rocker Arm mechanism was selected based on:

- Constraints
- Associated Costs
- Fabrication Time

In its core, the mechanism is essentially a 4 – bar mechanism as shown in figure E.1. This is implemented as a simple gear train with the pinion being connected to a driving disc which is in turn coupled with the main lever of the pump. The driving gear rotates the pinion which in turn rotates the driving disc which, via the coupler causes the main lever to oscillate. This is depicted in Figure E.2.

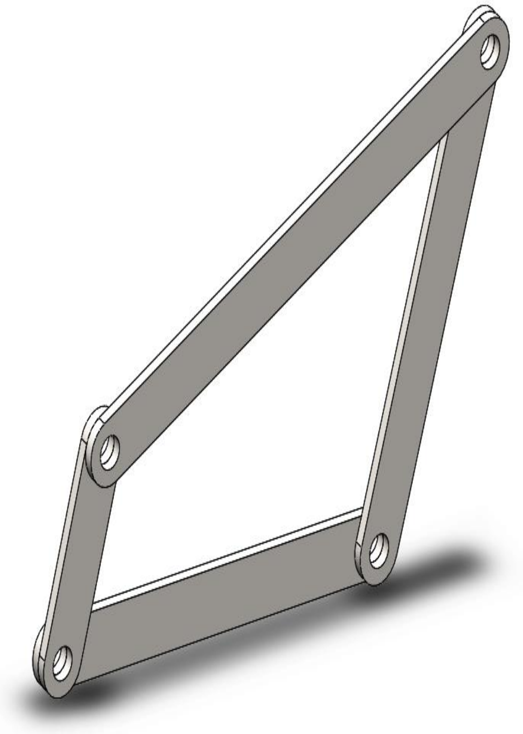

FIGURE E.1: *A four bar linkage,*

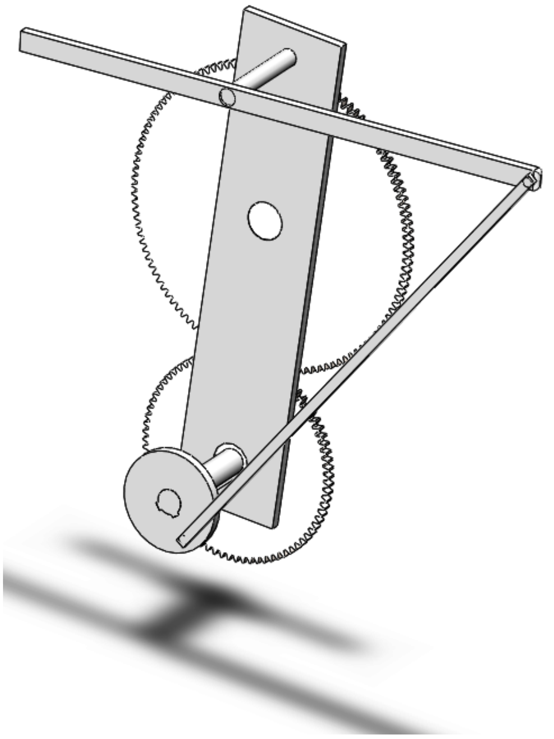

FIGURE E.2: *Actual Mechanism.*

F. FORCE AND TORQUE ANALYSIS

The following mechanism shall experience loading as shown in figure F.1. Image a loading-lever being mounted on the gear’s periphery such that torque can be applied by manual labour. Let this force be $F_{applied}$ and let it be applied at a distance of l_1 from the center. Let the angle between F_t and F_l be Θ and that between F_l and F_{eq} be α.

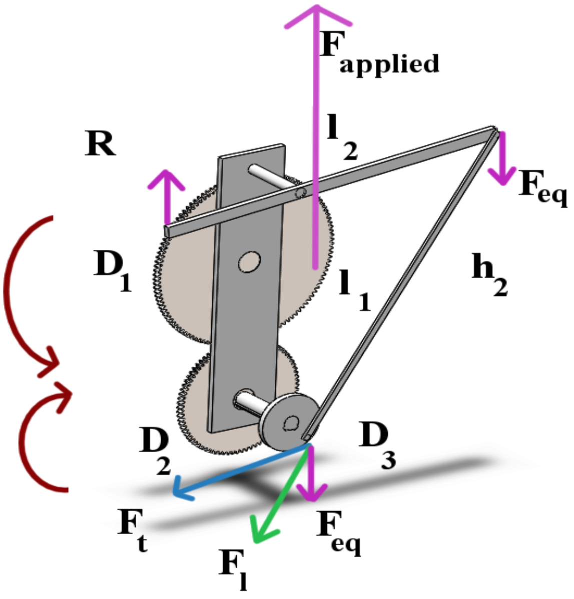

FIGURE F.1: *Force Analysis*

Then,

$$\tau_1 = F_{app} l_1 \tag*{Eq I}$$

$$\tau_2 = \left(\frac{\omega_1}{\omega_2}\right)\tau_{21} \tag*{Eq II}$$

$$\frac{\omega_1}{\omega_2} = \frac{Z_2}{Z_1} \tag*{Eq III}$$

$$\tau_2 = \left(\frac{Z_2}{Z_1}\right)\tau_{21} \tag*{Eq IV}$$

Now,

$$F_\tau = \frac{2}{D_3}\tau_2 \tag*{Eq V}$$

$$F_l = F_\tau \cos \Theta \tag*{Eq VI}$$

$$F_{eq} = F_l \cos \alpha \tag*{Eq VII}$$

$$\tau_{fin} = F_{eq} l_2 = \frac{2\, l_2}{D_3}\left(\frac{Z_2}{Z_1}\right)\tau_1 \cos \alpha \cos \Theta \tag*{Eq VIII}$$

$$\tau_{fin} = F_{app} \frac{2\, l_1 l_2}{D_3} \left(\frac{Z_2}{Z_1}\right) \cos\alpha \cos\Theta \qquad \text{Eq IX}$$

This is the expression for the final torque. Now, to check whether this mechanism provides us with any leverage, we need to calculate its mechanical advantage. The MA for this mechanism is defined as,

$$MA = \frac{\tau_{fin}}{F_{app} l_2} = \frac{2\, l_1}{D_3} \left(\frac{Z_2}{Z_1}\right) \cos\alpha \cos\Theta \qquad \text{Eq X}$$

Now, this mechanism will only provide leverage for MA $\geq$ 1. In such case,

$$2\, l_1 Z_2 \cos\alpha \cos\Theta \geq D_3 Z_1 \qquad \text{Eq XI}$$

For gears, $Z \propto D$. Therefore,

$$2\, l_1 D_2 \cos\alpha \cos\Theta \geq D_3 D_1 \qquad \text{Eq XII}$$

We Know,

$$l_1 \leq D_1 \qquad \text{Eq XIII}$$

$$l_1 = x D_1 \text{ Where} x \leq 1 \qquad \text{Eq XIV}$$

$$2\, l_1 \geq \frac{D_3 D_1}{Z_2} \sec\alpha \sec\Theta \qquad \text{Eq XV}$$

$$2x D_1 \geq \frac{D_3 D_1}{D_2} \sec\alpha \sec\Theta \qquad \text{Eq XVI}$$

Or,

$$D_3 \leq 2D_2 \cos\alpha \cos\Theta \qquad \text{Eq XVII}$$

Thus, for $MA \geq 1$,

$$D_3 \leq 2D_2 \cos\alpha \cos\Theta \qquad \text{Eq XVII}$$

For better understanding, its Motion-Analysis was simulated in SolidWorks with the following specifications:

- D_1 = 600 mm
- D_2 = 400 mm
- D_3 = 200 mm
- Module = 5 mm
- Face width = 20 mm
- Pressure angle = 20 °
- $\omega_{Driving}$ = 20 RPM
- Main coupler length h_2 = 1170 mm

- Main Lever length = 1140 mm
- Leverage length l_2 = 600 mm
- Height of the main lever = 1000 mm

For this simulation, some data from Dr. Sheppard's report [24] were taken as reference. For example, He hypothesized that the height of the main lever should be within 0.8 to 1.4 m and that on average, a human can apply a force of 350 N. To obtain leverage, the main lever was hinged 600 mm away from the coupling point, making the arm connected with the plunger of the pump have a length of ≈ 400 mm. From the initial motion analysis, the following data were obtained.

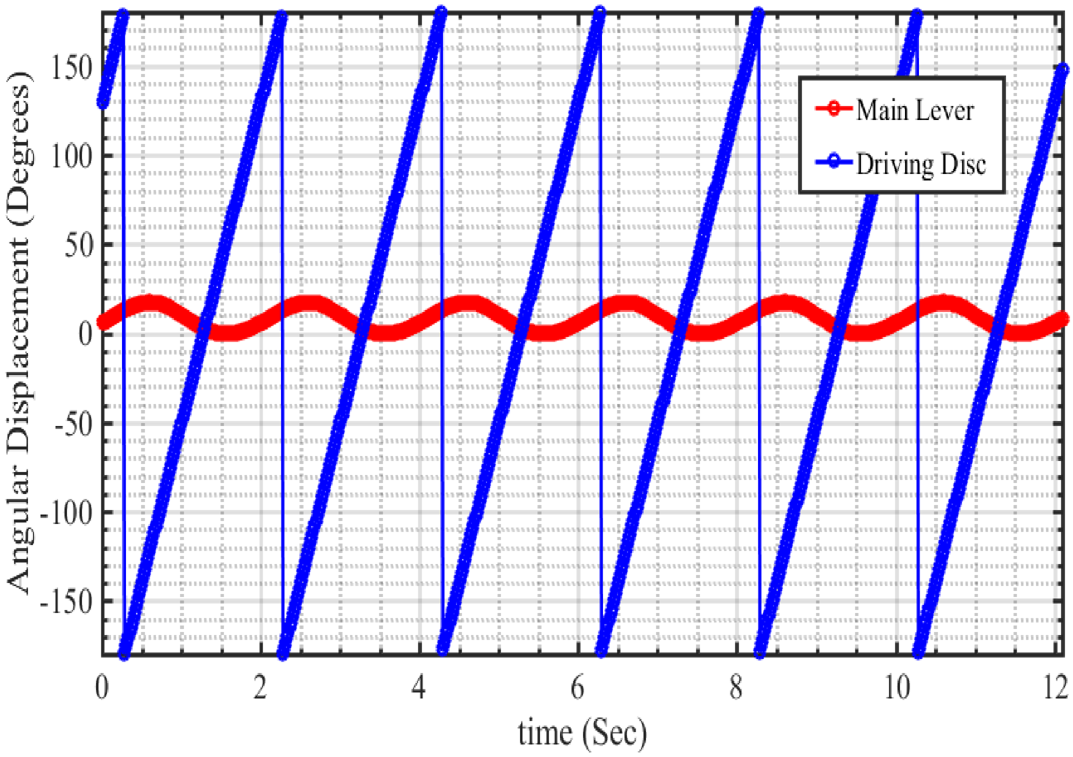

FIGURE F.2: *Motion Analysis*

As we can see from Figure F.2, during an angular displacement of the driving disc from -180° to 180°, the main lever undergoes a net displacement of 0° (+4.24°, -17°, +12.76°). It was found that the main lever undergoes a maximum of 17° displacement in this case. To understand the dynamics, the motion of the coupler was studied. The results obtained is shown in Figure F.3 below.

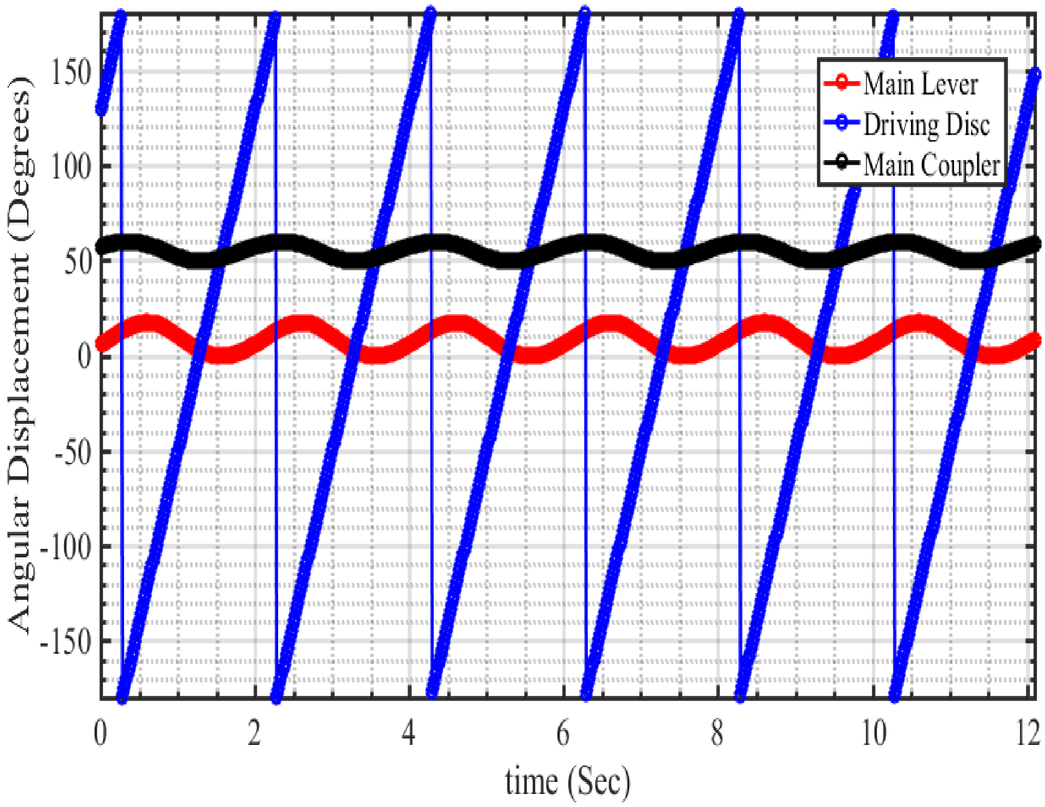

FIGURE F.3: *Dynamic Analysis*

The angular displacement of the main coupler, the driving disc and the main lever is tabulated in APPENDIX I.

After an elaborative regressive analysis, the angular displacement of the Driving disc and that of main lever seemed to share no relation other than their periodicity. The main lever was found to undergo a maximum displacement of 17.66926°. However, it will of course be subjected to changes depending upon the length and diameter of the driving disc. The result was obtained with a precision of 16.6 mSec.

For analysis of the forces, the motion of the main coupler was studied in detail. For any point in its trajectory, the forces act as shown in Figure F.5, where, F_T is the tangential force due to torque, F_L is the force along the main coupler, and F_{eq} is the equivalent force which actually acts perpendicular to the lever providing the final torque. From the diagram, we can derive the following conclusion

$$\alpha = 90 + \emptyset - \gamma \qquad \text{Eq XVIII}$$

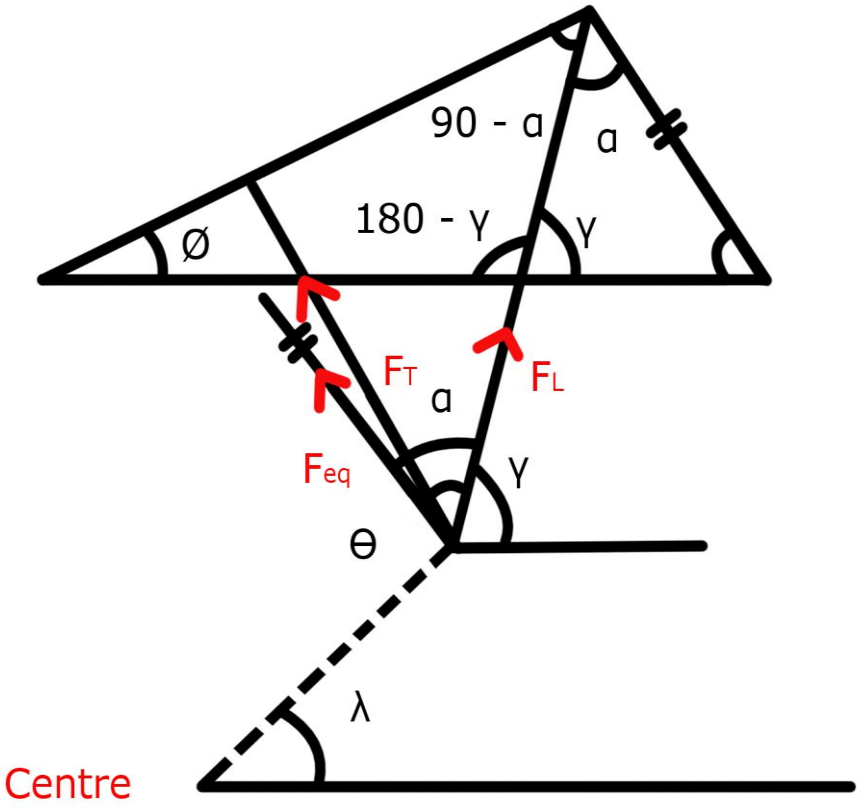

FIGURE F.4: *Force Diagram*

For detailed motion analysis, Θ and 90 – α were measured, the results of which are tabulated in APPENDIX II

It was found that

$$0° \leq \Delta\Theta \ \leq \ 360°$$

and

$$0° \leq \Delta\alpha \ \leq \ 13°$$

Using the specifications of the setup and equation X, we get the mechanical advantage as,

$$MA \ = \ 2cos \ \alpha \ cos \ \Theta$$

Calculating its value and integrating it over a full revolution, we get,

$$MA \ = \ 1.748049302.$$

Thus, we can see that over a period of 1 cycle, this mechanism will provide huge leverage of nearly 74.8% extra as compared to the original conventional setup. It was also noticed that per revolution of the driving disc, the lever oscillated ≈ 3.8 times. Together, we can conclude that this mechanism is indeed helpful, and it significantly improves the operation of a manually operated reciprocating pump.

Now for torque analysis, we know from equation X that

$$MA \times F_{app} l_2 = \tau_{fin}$$

We know, from [24] that an average human can apply as much as 340 N for manually operated reciprocating pumps. Now then, for l_2 = 600 mm, we get

$$\tau_{fin} = 356.602\ Nm$$

Therefore, the finally obtained plunging force (the force with which the plunger is pulled or pushed up or down) F_p is

$$F_p = 891.5\ N$$

The conventional plunging force would have been

$$F_{pc} = \frac{600 \times F_{app}}{400} = 510\ N$$

Thus, we get an increase in plunging force of

$$F_p - F_{pc} = 381.5\ N$$

That is, after using this mechanism, it’s as though instead of 1, nearly 2 persons are labouring at once.

RESULT OF ANALYSIS FOR THE GIVEN CASE

- Maximum displacement of main lever = 17.66°
- Maximum displacement of the main coupler = 360°
- Plunging force = 891.5 N
- Final torque = 356.602 Nm
- Increase in plunging force = 381.5 N, i.e 74.8%
- Mechanical advantage Obtained = 1.748
- Extra advantage = 74.8%
- Oscillations of the crank per revolution of the main gear = 4
- Gain in oscillations = 3 per revolution

The results can be visualized by Figure F.3. Compared to before, now we are getting twice the amount of water for 4 times to make it a total of 8 times more water than a conventional handpump and that too with 74.8% less effort. We can now grasp truly the importance of this invention.

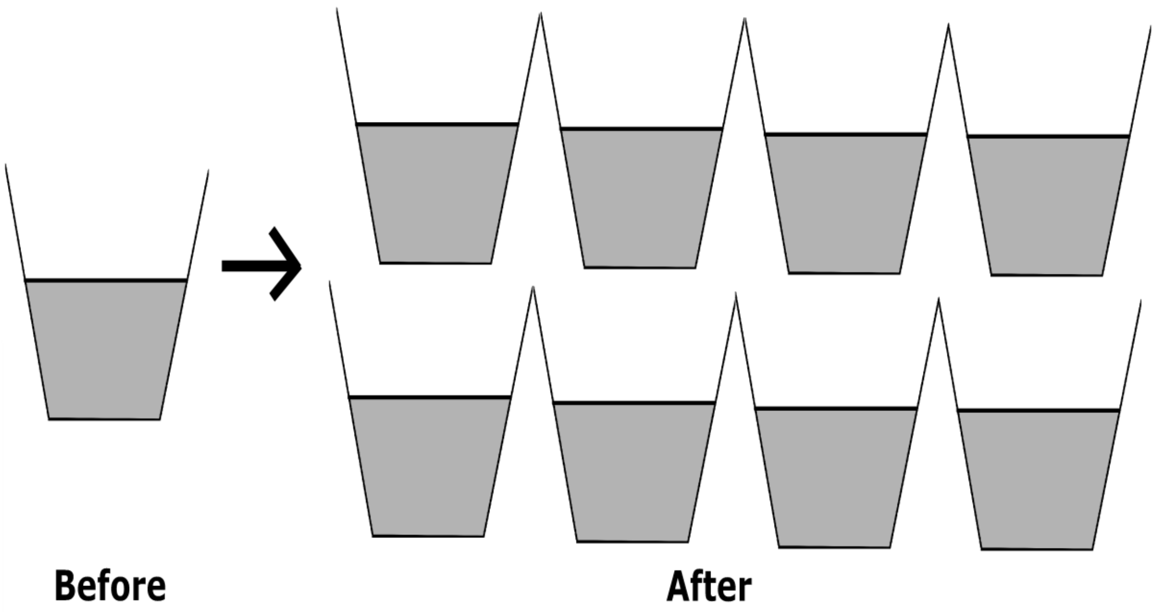

FIGURE F.3: *Result Visualization*

CHAPTER 3: DETAILED DIMENSIONING AND FABRICATION

G. DETAILED DIMENSIONING

Detailed dimensioning of each component is as follows. Before we begin though, we want to recall how other dimensions for the mechanism to work was possible as well provided they satisfied all the geometric, ergonomic, and kinematic constraints. The given set of dimensions has been tried and tested and are found to obey all the necessary constraints. Lastly, all dimensions are in mm.

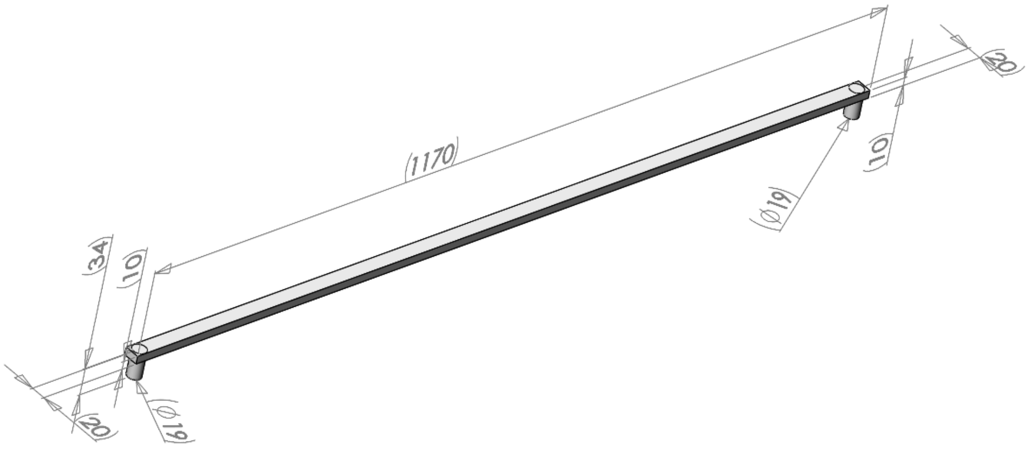

FIGURE G.1: *Coupler*

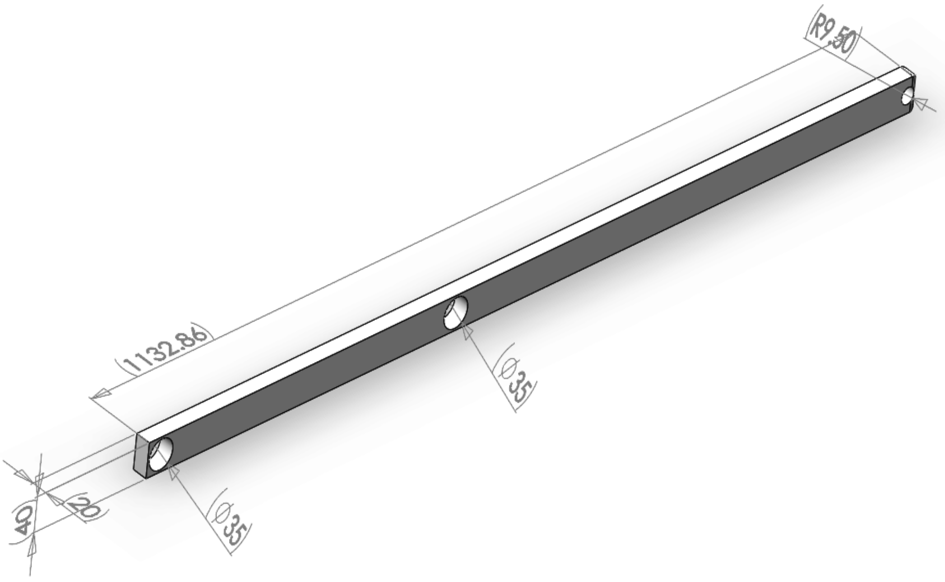

FIGURE G.2: *Main lever*

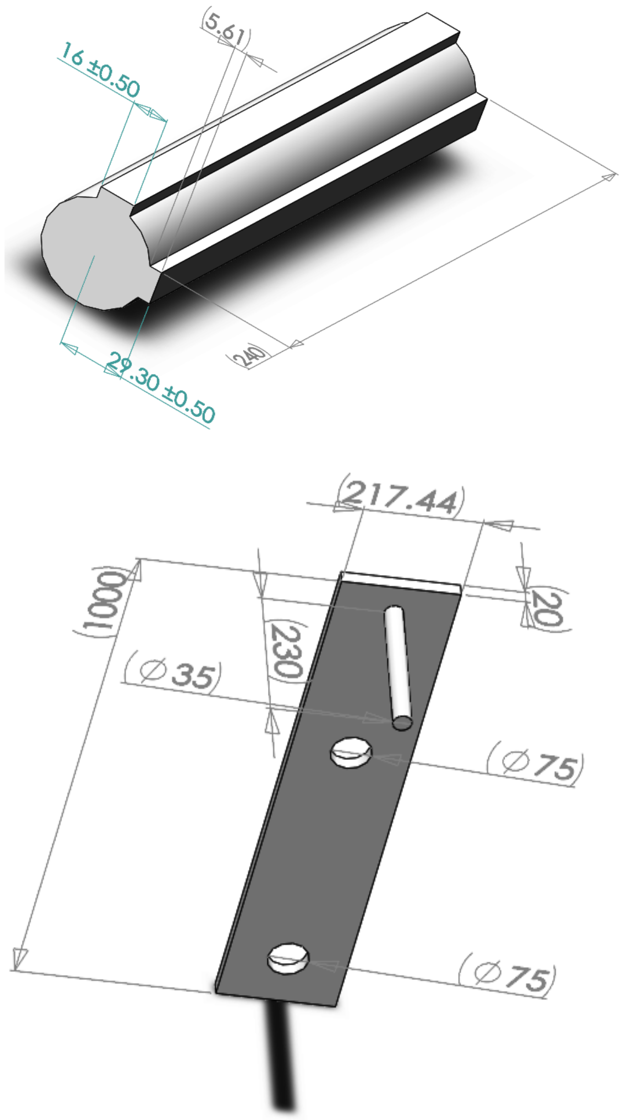

FIGURE G.3: *(Bottom) Structural Support, and (Up) Driving Shaft*

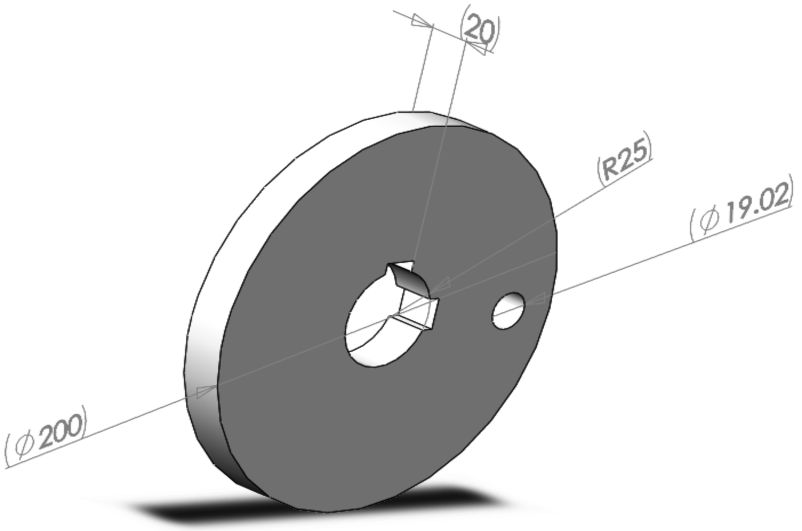

FIGURE G.4: *Driving Disc*

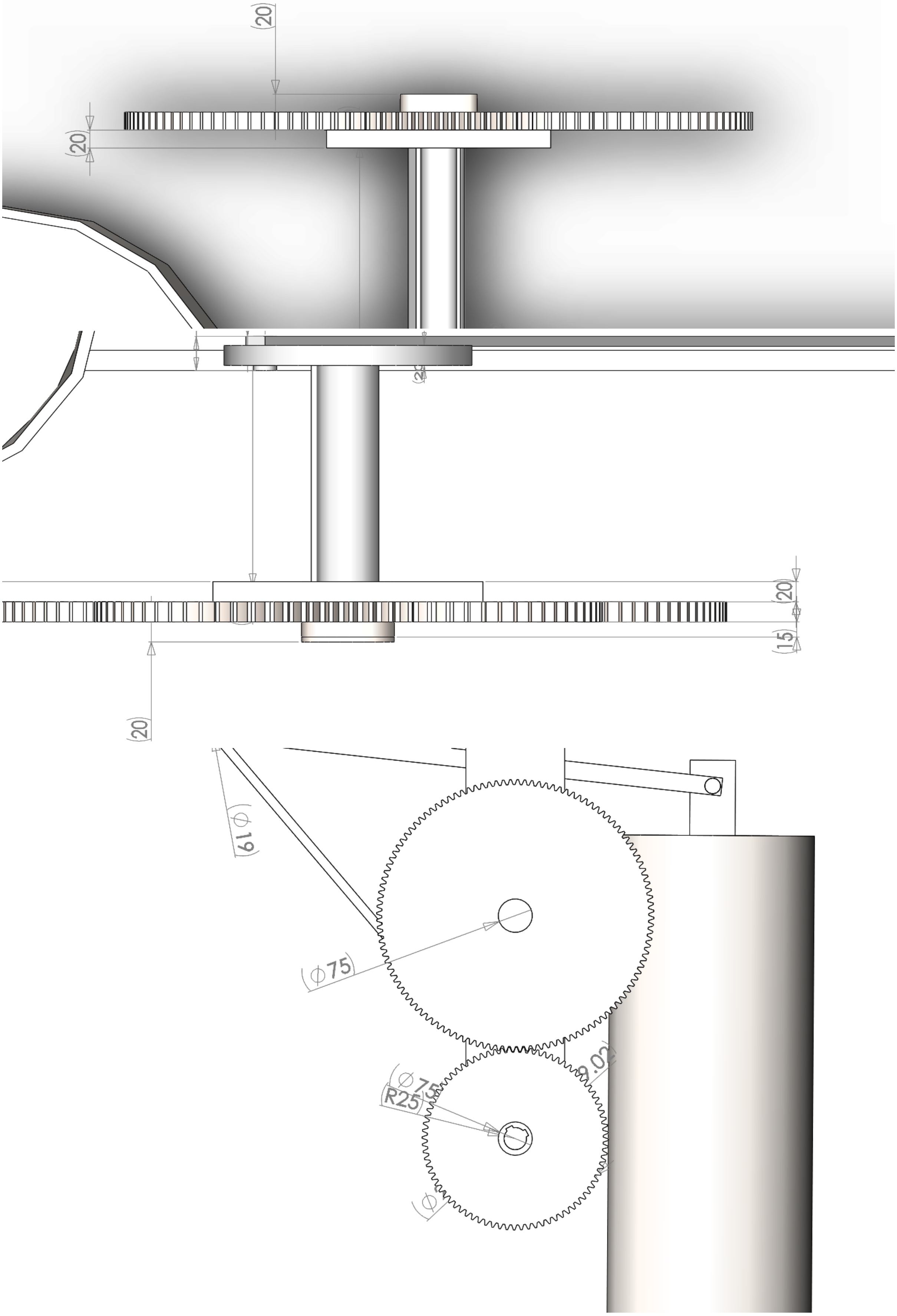

FIGURE G.5: *Gear Assembly*

H. DETAILED FABRICATION

When we went for fabrication, the very first hurdle that we faced was the material selection itself. As stated earlier, our preferred choice for fabrication was aluminum however, when we went for fabrication, scraps of aluminum of the required dimensions were not available. If we were to do it with aluminum, the only option was to cast the blank ourselves. This would have extremely increased our project cost which would have been beyond what any of us could ever afford. Therefore, for prototyping, we had to reluctantly go mild steel.

The essential additions that were incorporated during fabrication were:

a. **Ball bearings:** We realized that while it was feasible to do without a bearing in a precisely machined setup, for a rough prototyping to work, ball bearings were essential. For this setup, the bearings used were 6211 and 6216

b. **Washers:** Another realization to dawn upon us were that to hold the main lever and the coupler in its place, we needed some sort of washers which would sandwich them and will prevent them from angular deflection. The washers used were 1mm-2cm washers.

There were also some critical decisions made which were

a. Another important aspect of the whole fabrication process was the type of welding. With all the popular options like GMAW, SMAW and Gas welding available, we had to choose the correct one. Firstly, due to majority of the structural parts being thicker that 3 mm, gas welding was out of question. Again, due to the relative bulk of the prototype, majority of the work had to be done outdoors because of which GMAW weld was not a viable option. Thus, we were left with SMAW electric arc welding.

b. Yet another problem that we encountered were that of bend in the shafts. Procuring a shaft without a bend was almost impossible without casting one ourselves. The only other way was therefore to machine out the bend. When we went for machine, owing to the huge diameters of each of them, we couldn't find a lathe machine in the vicinity of the workshop that could mount them and hence, we had re think our approach. Ultimately, we settled on a crude combination of heating, beating, quenching and rough surface finishing to even out the bends.

c. The final problem that we faced were bending in gears. Mild steel being a soft and malleable metal, when machined into gears as big as 60 cm was bound experience bending. It was not something unexpected but was surely something we were not prepared for. The only way in the end was to give offset to the bearing itself such that it cancels out the lateral deflection. The radial deflection could not be corrected no made what and had therefore to be accounted for in the final design in terms of effective surface contact between two meshing teeth thereby reducing their beam and wear strength.

Summarized below are the properties of the prototype:

1. Mass properties:

a. Mount	33.3 kg
b. 3’’ shaft	8 kg
c. 2’’ shaft	3 kg
d. Driving gear	21 kg
e. Pinion gear	9 kg
f. Driving disc	2.3 kg
g. Angle bracket	3 kg
h. Lever and coupler	5 kg
Total:	84.6 kg

2. Cost:

a. Procurement cost = Rs 55/kg, Rs 6300/Gears	Rs 10953
b. Machining cost = Rs 1500/Welding, Rs 400/Lathe, Rs 100/ Drill,	Rs 2000
c. Tool cost = 250/ Drill bit, 750, 180/ Ball bearings	Rs 1180
d. Transportation cost	Rs 2700
Total:	Rs 16833

3. Geometric properties:

a. 3’’ Shaft deflection	1.1 mm
b. 2’’ Shaft deflection	2 mm
c. Column deflection	2.8 mm
d. Bearing tilt	1.3 mm
e. Driving gear bend	1.1 mm
f. Pinion bend	0.8 mm
g. Hinge point angular tolerance	45°
h. Coupling point angular tolerance	51.34°
i. Disc point angular tolerance	34.77°

The photos of prototype can be found in the APPENDIX III

CHAPTER 4: FINAL DESIGN AND EXPERIMENTAL CORRECTIONS

I. FINAL DESIGN

After finishing with the fabrication and experimentation, we came up with this final design.

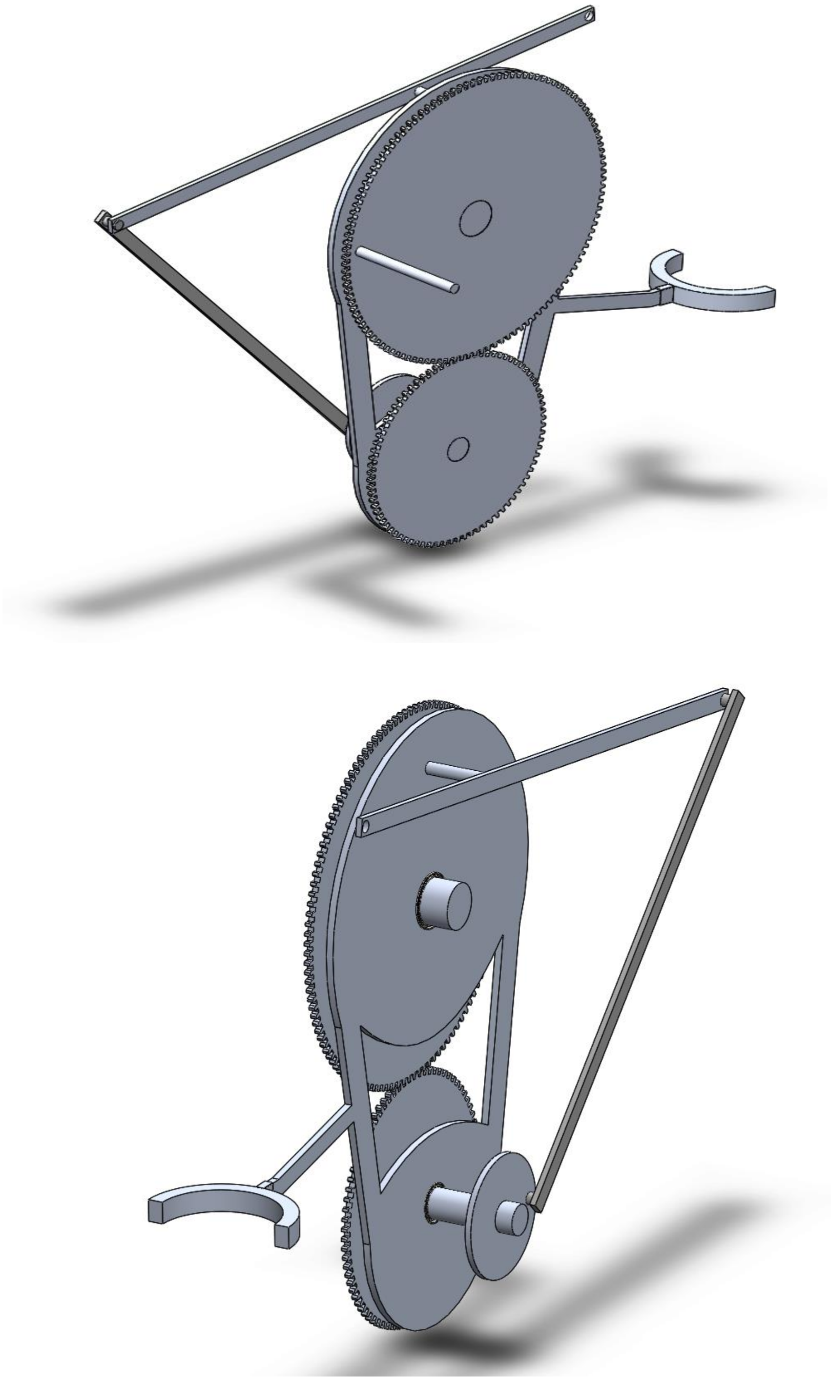

FIGURE I.1: *Final Design*

Analysing the data reveals the properties as:

- Total Mass = 28.7 kg
- Total Volume = 0.108 m^3
- Total Surface Area = 2.101588 m^2
- Total cost = Rs 6171

Considering the force due to gravity and the dynamic loading due to the manual effort, we get a total stress in the mounting hinge of 1.726 N/mm^2. As we can see, it is several orders of magnitude less that the yield strength of aluminium 1350 alloy which is 27.574 N/mm^2 Giving us a net FOS (factor of safety) of 15.97. accounting for cyclic loading, we still get a FOS of 5.325. Therefore, our design is safe and should last long no matter the circumstances.

J. EXPERIMENTAL CORRECTION

After several experimentation, the following two critical corrections were proposed:

- **Effective Wear Strength:** We know wear strength of spur gears are given by QbDK however, due to the overhang nature of the gears and deflection due to its large size, two further correction factors are defined. K_d(deflection factor) K_c(effective contact surface factor).
- **Effective leverage length:** Due to lateral and angular displacement, the effective leverage length decreases thereby decreasing the net leverage obtained. This happens because the net projected perpendicular length from the point of torque application to the hinge point decreases as the lever and driving disc deviates from its mean intended path. For this a new factor K_l (effective leverage length factor) must be introduced.

Incorporating them, the new equations for torque and MA becomes:

$$\tau_{fin} = \frac{K_c K_l}{K_d} F_{app} \frac{2\, l_1 l_2}{D_3} \left(\frac{Z_2}{Z_1}\right) \cos\alpha \cos\Theta \qquad \text{Eq XIX}$$

$$MA = \frac{K_c K_l}{K_d} \frac{2\, l_1}{D_3} \left(\frac{Z_2}{Z_1}\right) \cos\alpha \cos\Theta \qquad \text{Eq XX}$$

This also effects the number of oscillations of main lever per revolution of driving gear as:

$$N_{corrected} = K_l N_{old} \qquad \text{Eq XXI}$$

Therefore, the FOS becomes:

$$FOS_{corrected} = \frac{K_c K_l}{K_d} FOS_{old} \qquad \text{Eq XXII}$$

The values of K_d, K_c and K_l were experimentally found to be 1.1, 0.75, and 0.5 respectively. Therefore, for the prototype, the new FOS becomes 1.81 and the new N becomes 2. Thus, our design, even with such high degree of error will still remain functional no matter what.

FEEDBACK

To ensure our project is actually important, we went to nearby villages and interviewed some locals regarding what they think of our work. Due to summer time, most of them were unavailable but we managed to find two school teachers and documented below are their translated unaltered testimonies.

Ummed Singh,

Teacher, Village school, Jamavagarh

"The biggest problem we face are that of electricity and water. If what you say is true then this will truly be remarkable and will indeed change all our lives. Perhaps the only project to be more important that this would be implementations of solar panels. We hope you succeed."

Ramesh Yadav,

Teacher, Village school, Pithalpur

"In Rajasthan, water level is low because of which hand pumps are not useful and borewells are needed to be implemented. But borewells are costly. Not all villages can afford to build more than one and even then, they run only for a small time. If you are able to increase the water sucking capacity of handpumps, then we can implement them and we all can afford to have a 24 hrs water supply. Best wishes."

FUTURE SCOPE

While we tried our best to achieve the preset objective, there will always remain scopes of future improvement. Enumerated below are some of the improvements which can be incorporated in future endeavors.

- The four-bar linkage can be attempted to be replaced by a six-bar linkage. This increases the kinematic advantage by reducing the number of locked configuration. This eliminates the kinematic constraints to a great extend and all this happens because the number of configurations forming a parallelogram is drastically reduced. Dijksman has discussed this to great details in [25].

- A spring exciter can be added for improving further the dynamic response of the system. Ahmedalbashir, M, et al discusses this extensively in [26].

- Lastly, we can also attempt to replace the big gear train with a more complex but also more compact compound-gear-train. This will reduce the gear size such that the effect of K_d, K_c and K_l gets minimized. That way we can optimize the setup for maximum leverage.

APPENDIX

APPENDIX I

Time (sec)	Ø	λ	γ
0	5.794506	130.0237	57.28919
0.016644	6.143858	132.578	57.46278
0.033287	6.577145	135.699	57.66885
0.049931	7.016162	138.817	57.86768
0.066575	7.459945	141.9325	58.05888
0.083219	7.904929	145.0278	58.24106
0.099862	8.336796	148.012	58.40896
0.116506	8.767614	150.9764	58.56786
0.13315	9.199117	153.9394	58.7185
0.149794	9.63046	156.9021	58.8606
0.166437	10.06072	159.8649	58.99384
0.183081	10.48893	162.8283	59.11791
0.199725	10.91414	165.7926	59.2325
0.216369	11.33533	168.7583	59.3373
0.233012	11.7515	171.7259	59.43198
0.249656	12.16159	174.6959	59.51624
0.2663	12.56455	177.6685	59.58976
0.282944	12.95928	-179.356	59.65223
0.299587	13.34507	-176.373	59.70336
0.316231	13.72121	-173.38	59.74286
0.332875	14.0858	-170.381	59.77028
0.349519	14.43747	-167.376	59.7853
0.366162	14.77498	-164.367	59.7876
0.382806	15.0971	-161.353	59.7769
0.39945	15.40257	-158.333	59.75292
0.416094	15.69014	-155.308	59.71538
0.432737	15.95856	-152.277	59.66406
0.449381	16.20659	-149.241	59.59874
0.466025	16.43299	-146.199	59.51924
0.482669	16.63657	-143.152	59.42543
0.499312	16.81617	-140.099	59.31721
0.515956	16.96886	-137.082	59.19622
0.5326	17.09455	-134.101	59.06309
0.549243	17.1946	-131.116	58.91638
0.565887	17.26823	-128.129	58.75622
0.582531	17.31473	-125.139	58.58283
0.599175	17.33355	-122.148	58.3965
0.615818	17.32424	-119.156	58.19759
0.632462	17.28649	-116.164	57.98658
0.649106	17.22016	-113.172	57.76398

0.66575	17.12523	-110.182	57.53042
0.682393	17.00187	-107.194	57.28658
0.699037	16.85041	-104.21	57.03323
0.715681	16.67134	-101.23	56.77121
0.732325	16.46528	-98.2542	56.50141
0.748968	16.23303	-95.284	56.22479
0.765612	15.97551	-92.3196	55.94235
0.782256	15.69378	-89.3616	55.65512
0.7989	15.38901	-86.4103	55.36416
0.815543	15.06246	-83.4659	55.07055
0.832187	14.71441	-80.5197	54.77448
0.848831	14.33875	-77.5143	54.47126
0.865475	13.94443	-74.5143	54.16851
0.882118	13.53305	-71.5194	53.86738
0.898762	13.10593	-68.5269	53.56879
0.915406	12.66395	-65.5316	53.27337
0.93205	12.2089	-62.5341	52.98234
0.948693	11.74295	-59.5373	52.69713
0.965337	11.26797	-56.5417	52.41889
0.981981	10.78556	-53.5462	52.14855
0.998624	10.29738	-50.5499	51.88707
1.015268	9.805157	-47.5527	51.6354
1.031912	9.310799	-44.5555	51.39454
1.048556	8.816072	-41.5588	51.16534
1.065199	8.322584	-38.562	50.94855
1.081843	7.831865	-35.5646	50.74484
1.098487	7.345368	-32.5659	50.55479
1.115131	6.864501	-29.5653	50.37895
1.131774	6.390615	-26.5621	50.21778
1.148418	5.925005	-23.5556	50.07171
1.165062	5.468919	-20.5454	49.94108
1.181706	5.023553	-17.5308	49.82619
1.198349	4.590053	-14.5114	49.72729
1.214993	4.169512	-11.4868	49.64454
1.231637	3.76297	-8.4567	49.57809
1.248281	3.371412	-5.42085	49.52797
1.264924	2.995771	-2.37904	49.49421
1.281568	2.636919	0.668871	49.47674
1.298212	2.295944	3.720506	49.47545
1.314856	1.979421	6.718618	49.48972
1.331499	1.682795	9.705934	49.51896
1.348143	1.405175	12.69543	49.56289
1.364787	1.146816	15.6896	49.62124
1.381431	0.908142	18.68884	49.69367
1.398074	0.689662	21.69174	49.77977
1.414718	0.492087	24.69218	49.87888

1.431362	0.316134	27.68001	49.99011
1.448006	0.161052	30.6684	50.11333
1.464649	0.026889	33.65914	50.24812
1.481293	-0.08626	36.65285	50.39399
1.497937	-0.17831	39.64925	50.5504
1.51458	-0.2492	42.64797	50.71677
1.531224	-0.29893	45.6485	50.89253
1.547868	-0.32754	48.64933	51.077
1.564512	-0.33516	51.6494	51.26952
1.581155	-0.32202	54.64183	51.46903
1.597799	-0.28834	57.6339	51.67538
1.614443	-0.23436	60.62527	51.88798
1.631087	-0.16036	63.61547	52.10618
1.64773	-0.06665	66.60407	52.32937
1.664374	0.046437	69.5909	52.55696
1.681018	0.17851	72.57562	52.78834
1.697662	0.329164	75.55791	53.0229
1.714305	0.497955	78.5374	53.26008
1.730949	0.684412	81.5138	53.49928
1.747593	0.888035	84.48686	53.73995
1.764237	1.108303	87.45633	53.98154
1.78088	1.34467	90.42203	54.22352
1.797524	1.596571	93.38378	54.46537
1.814168	1.863418	96.34145	54.70659
1.830812	2.14461	99.29495	54.94669
1.847455	2.439525	102.2442	55.18521
1.864099	2.752371	105.2345	55.42532
1.880743	3.080259	108.2404	55.66445
1.897387	3.420413	111.2418	55.90053
1.91403	3.772126	114.2388	56.13313
1.930674	4.134666	117.2316	56.36183
1.947318	4.507282	120.2202	56.58623
1.963961	4.889768	123.2091	56.80624
1.980605	5.282103	126.2038	57.02185
1.997249	5.682959	129.2	57.23231
2.013893	6.091422	132.1969	57.43716
2.030536	6.506535	135.1936	57.63595
2.04718	6.927366	138.1895	57.82825
2.063824	7.35306	141.185	58.01371
2.080468	7.782836	144.1809	58.19201
2.097111	8.215753	147.1772	58.36277
2.113755	8.650848	150.1738	58.52563
2.130399	9.087128	153.1706	58.68022
2.147043	9.523557	156.1674	58.82617
2.163686	9.959138	159.1644	58.96315
2.18033	10.39287	162.1619	59.09083

2.196974	10.82375	165.1602	59.20887
2.213618	11.25074	168.16	59.31696
2.230261	11.67279	171.1615	59.41477
2.246905	12.08883	174.1652	59.50197
2.263549	12.49777	177.1716	59.57824
2.280193	12.89847	-179.819	59.64325
2.296836	13.28979	-176.806	59.69667
2.31348	13.67056	-173.788	59.73817
2.330124	14.03957	-170.767	59.76744
2.346768	14.39559	-167.741	59.78415
2.363411	14.73739	-164.71	59.78799
2.380055	15.0637	-161.673	59.77866
2.396699	15.37325	-158.631	59.75588
2.413343	15.66475	-155.584	59.71936
2.429986	15.93444	-152.559	59.66942
2.44663	16.18083	-149.569	59.60647
2.463274	16.4056	-146.584	59.53008
2.479917	16.60835	-143.596	59.44001
2.496561	16.78816	-140.605	59.33611
2.513205	16.94402	-137.609	59.21835
2.529849	17.07495	-134.608	59.08671
2.546492	17.18004	-131.604	58.94127
2.563136	17.25847	-128.597	58.78218
2.57978	17.30938	-125.599	58.61031
2.596424	17.33248	-122.608	58.42594
2.613067	17.32755	-119.62	58.22927
2.629711	17.29432	-116.634	58.02052
2.646355	17.23263	-113.648	57.80017
2.662999	17.14246	-110.664	57.56879
2.679642	17.02395	-107.682	57.32707
2.696286	16.87739	-104.704	57.07575
2.71293	16.70323	-101.729	56.81566
2.729574	16.50208	-98.7583	56.54765
2.746217	16.2747	-95.7932	56.27269
2.762861	16.02199	-92.8338	55.99176
2.779505	15.74497	-89.8807	55.70587
2.796149	15.4448	-86.9342	55.41609
2.812792	15.1227	-83.9945	55.12346
2.829436	14.77372	-81.0096	54.82383
2.84608	14.40212	-78.0102	54.52133
2.862724	14.01165	-75.016	54.21909
2.879367	13.60328	-72.0221	53.91781
2.896011	13.17806	-69.025	53.61828
2.912655	12.7381	-66.0278	53.32202
2.929298	12.28527	-63.0318	53.0303
2.945942	11.82121	-60.0363	52.74417

2.962586	11.34762	-57.0405	52.46469
2.97923	10.86608	-54.0434	52.19283
2.995873	10.37853	-51.046	51.92971
3.012517	9.886909	-48.0493	51.67638
3.029161	9.392904	-45.0529	51.43372
3.045805	8.898157	-42.0562	51.20255
3.062448	8.404302	-39.0591	50.98363
3.079092	7.912901	-36.0612	50.77766
3.095736	7.425471	-33.0619	50.58526
3.11238	6.943438	-30.0608	50.40698
3.129023	6.468167	-27.0572	50.24331
3.145667	6.000974	-24.0504	50.09468
3.162311	5.543108	-21.04	49.96145
3.178955	5.095777	-18.0252	49.84393
3.195598	4.660133	-15.0058	49.74237
3.212242	4.23728	-11.9812	49.65695
3.228886	3.828268	-8.95121	49.58781
3.24553	3.434092	-5.91545	49.53502
3.262173	3.055693	-2.87375	49.49858
3.278817	2.693956	0.17403	49.47847
3.295461	2.349991	3.225408	49.47457
3.312105	2.030687	6.220787	49.4863
3.328748	1.73087	9.208471	49.51306
3.345392	1.449913	12.19915	49.5546
3.362036	1.18817	15.19439	49.61062
3.37868	0.946067	18.19469	49.68079
3.395323	0.724465	21.19375	49.76457
3.411967	0.523669	24.19053	49.86142
3.428611	0.343903	27.18395	49.9708
3.445254	0.184966	30.17994	50.09239
3.461898	0.047042	33.17816	50.22569
3.478542	-0.06948	36.1709	50.36979
3.495186	-0.16489	39.1657	50.52448
3.511829	-0.23915	42.16222	50.68918
3.528473	-0.29225	45.15835	50.86321
3.545117	-0.32428	48.15454	51.04601
3.561761	-0.33535	51.15028	51.23695
3.578404	-0.32563	54.14473	51.43539
3.595048	-0.29532	57.13886	51.64079
3.611692	-0.24464	60.13225	51.85253
3.628336	-0.17386	63.12472	52.07
3.644979	-0.08329	66.11592	52.29259
3.661623	0.02675	69.10546	52.51969
3.678267	0.155874	72.09294	52.75067
3.694911	0.303675	75.078	52.98495
3.711554	0.469715	78.0603	53.22193

3.728198	0.653526	81.03956	53.46103
3.744842	0.854611	84.0155	53.7017
3.761486	1.072453	86.98789	53.94337
3.778129	1.306506	89.95652	54.18551
3.794773	1.556207	92.92123	54.4276
3.811417	1.820973	95.88187	54.66914
3.828061	2.100199	98.83835	54.90964
3.844704	2.393269	101.7906	55.14862
3.861348	2.69966	104.7396	55.38572
3.877992	3.023094	107.7249	55.62361
3.894635	3.361548	110.7301	55.86049
3.911279	3.7123	113.7359	56.09434
3.927923	4.074053	116.7374	56.32433
3.944567	4.446051	119.7346	56.55006
3.96121	4.827546	122.7278	56.77113
3.977854	5.217839	125.7178	56.9872
3.994498	5.616279	128.7057	57.19796
4.011142	6.023372	131.7012	57.40368
4.027785	6.437839	134.7007	57.60368
4.044429	6.858054	137.6987	57.7972
4.061073	7.283159	140.6952	57.98387
4.077717	7.712268	143.6906	58.16334
4.09436	8.144595	146.6859	58.33531
4.111004	8.579275	149.6816	58.49944
4.127648	9.015377	152.678	58.65539
4.144292	9.451927	155.6753	58.80282
4.160935	9.887876	158.6734	58.94134
4.177579	10.32213	161.6718	59.0706
4.194223	10.75369	164.671	59.19028
4.210867	11.18152	167.6714	59.30005
4.22751	11.6046	170.6737	59.39959
4.244154	12.02184	173.6781	59.48857
4.260798	12.43215	176.6851	59.56666
4.277442	12.83441	179.6953	59.63353
4.294085	13.22747	-177.291	59.68886
4.310729	13.61015	-174.273	59.73232
4.327373	13.98126	-171.252	59.76359
4.344017	14.33958	-168.225	59.78233
4.36066	14.68386	-165.194	59.78825
4.377304	15.01284	-162.157	59.78104
4.393948	15.32525	-159.115	59.76041
4.410591	15.61981	-156.067	59.72607
4.413581	15.67073	-155.519	59.71844
4.427235	15.89183	-153.053	59.6785
4.443879	16.14151	-150.064	59.61782
4.460523	16.36998	-147.077	59.54364

4.477166	16.57663	-144.087	59.45573
4.49381	16.76048	-141.092	59.35398
4.510454	16.92049	-138.093	59.23832
4.527098	17.05567	-135.09	59.10875
4.543741	17.16492	-132.088	58.96559
4.560385	17.24745	-129.091	58.80924
4.577029	17.3028	-126.099	58.63992
4.593673	17.33057	-123.107	58.45762
4.610316	17.33031	-120.114	58.26265
4.62696	17.30169	-117.122	58.05543
4.643604	17.24451	-114.13	57.83647
4.660248	17.15873	-111.139	57.60635
4.676891	17.04445	-108.151	57.36572
4.693535	16.90194	-105.165	57.11533
4.710179	16.73164	-102.184	56.85599
4.726823	16.53414	-99.2064	56.58858
4.743466	16.31018	-96.2343	56.31404
4.76011	16.06064	-93.2679	56.03334
4.776754	15.78653	-90.3077	55.74752
4.793398	15.48899	-87.3542	55.45763
4.810041	15.16926	-84.4074	55.16474
4.826685	14.82866	-81.4677	54.86994
4.843329	14.4656	-78.5114	54.57192
4.859972	14.07753	-75.5113	54.26906
4.876616	13.67016	-72.504	53.96619
4.89326	13.24703	-69.5038	53.66594
4.909904	12.80985	-66.5103	53.36944
4.926547	12.36008	-63.5214	53.07761
4.943191	11.89853	-60.5308	52.79098
4.959835	11.42663	-57.5366	52.51047
4.976479	10.94597	-54.5378	52.2371
4.993122	10.45881	-51.5375	51.97221
5.009766	9.967296	-48.538	51.71699
5.02641	9.473398	-45.5405	51.47245
5.043054	8.978723	-42.5443	51.23939
5.059697	8.484823	-39.5486	51.01852
5.076341	7.993209	-36.5526	50.8105
5.092985	7.505349	-33.5556	50.61596
5.109629	7.022659	-30.5569	50.43544
5.126272	6.546498	-27.5557	50.26944
5.142916	6.078182	-24.5515	50.11838
5.15956	5.618974	-21.5437	49.98265
5.176204	5.170087	-18.5317	49.86255
5.192847	4.732685	-15.515	49.75836
5.209491	4.307875	-12.4933	49.67026
5.226135	3.896714	-9.46621	49.5984

5.242779	3.500204	-6.43343	49.54286
5.259422	3.119295	-3.39474	49.50366
5.276066	2.754878	-0.35	49.48077
5.29271	2.407791	2.700888	49.47409
5.309354	2.081641	5.730895	49.48333
5.325997	1.780169	8.703958	49.5075
5.342641	1.497058	11.68252	49.54639
5.359285	1.232848	14.66661	49.59972
5.375928	0.988037	17.65604	49.66718
5.392572	0.763072	20.65062	49.74841
5.409216	0.558349	23.65003	49.843
5.42586	0.374209	26.65395	49.95053
5.442503	0.210935	29.66201	50.07053
5.459147	0.068759	32.67383	50.20248
5.475791	-0.05191	35.68265	50.34555
5.492435	-0.15078	38.67741	50.49857
5.509078	-0.22836	41.66793	50.66135
5.525722	-0.28486	44.65866	50.83356
5.542366	-0.32036	47.6506	51.01467
5.55901	-0.33494	50.64336	51.20409
5.575653	-0.32873	53.63642	51.4012
5.592297	-0.30192	56.62956	51.60539
5.608941	-0.2547	59.62235	51.81604
5.625585	-0.18735	62.61439	52.03253
5.642228	-0.10014	65.60521	52.25425
5.658872	0.006571	68.59441	52.48056
5.675516	0.132429	71.58161	52.71088
5.69216	0.277029	74.56643	52.94458
5.708803	0.439936	77.54857	53.18108
5.725447	0.620688	80.52771	53.41981
5.742091	0.818795	83.50357	53.66019
5.758735	1.033741	86.47593	53.90167
5.775378	1.264987	89.44456	54.14372
5.792022	1.511973	92.4093	54.3858
5.808666	1.774118	95.37	54.62742
5.825309	2.050824	98.32654	54.86808
5.841953	2.341475	101.2789	55.1073
5.858597	2.646536	104.2373	55.34547
5.875241	2.968856	107.2325	55.58454
5.891884	3.304771	110.2336	55.82155
5.908528	3.653037	113.2351	56.05561
5.925172	4.012672	116.2345	56.28606
5.941816	4.382703	119.23	56.51235
5.958459	4.762449	122.2223	56.73412
5.975103	5.151456	125.2139	56.95114
5.991747	5.549884	128.2119	57.1635

6.008391	5.956295	131.2112	57.37043
6.025034	6.369483	134.2091	57.57133
6.041678	6.788406	137.2044	57.76575
6.058322	7.212309	140.198	57.95338
6.074966	7.640504	143.1914	58.13394
6.091609	8.072659	146.1888	58.3073
6.108253	8.507423	149.1872	58.47291
6.124897	8.943643	152.1855	58.63034
6.141541	9.380268	155.1832	58.77921
6.158184	9.816333	158.1807	58.91921
6.174828	10.25086	161.1785	59.04999
6.191472	10.68286	164.1771	59.17125
6.208116	11.11132	167.1768	59.28266
6.224759	11.53518	170.1783	59.38389
6.241403	11.9534	173.1818	59.47462
6.258047	12.36486	176.1879	59.55452
6.274691	12.76847	179.1971	59.62326
6.291334	13.16307	-177.79	59.68051
6.307978	13.54749	-174.774	59.72595
6.324622	13.92055	-171.753	59.75926
6.341265	14.28101	-168.728	59.7801
6.357909	14.62766	-165.698	59.78817
6.374553	14.95922	-162.662	59.78316
6.391197	15.27443	-159.622	59.76479
6.40784	15.57201	-156.575	59.73276
6.424484	15.84824	-153.551	59.68731
6.441128	16.10195	-150.554	59.62871
6.457772	16.33435	-147.562	59.55661
6.474415	16.54495	-144.567	59.47078
6.491059	16.73272	-141.57	59.37115
6.507703	16.89649	-138.574	59.25779
6.524347	17.03544	-135.578	59.13074
6.54099	17.14871	-132.583	58.99014
6.557634	17.23562	-129.588	58.8361
6.574278	17.29555	-126.593	58.66875
6.590922	17.32792	-123.598	58.48838
6.607565	17.33228	-120.603	58.29531
6.624209	17.30828	-117.608	58.08993
6.640853	17.25571	-114.614	57.87272
6.657497	17.17452	-111.622	57.64425
6.67414	17.06478	-108.632	57.40518
6.690784	16.92677	-105.646	57.15626
6.707428	16.76087	-102.663	56.89825
6.724072	16.56766	-99.6841	56.63202
6.740715	16.34784	-96.7105	56.3585
6.757359	16.10228	-93.7426	56.07866

6.774003	15.83197	-90.7808	55.79353
6.790646	15.53804	-87.8255	55.50416
6.80729	15.2217	-84.8771	55.21162
6.823934	14.88427	-81.9357	54.91699
6.840578	14.52702	-79.0003	54.62127
6.857221	14.14323	-76.0091	54.3193
6.873865	13.73876	-73.0015	54.0162
6.890509	13.31826	-70.0011	53.71553
6.907153	12.88342	-67.0074	53.41842
6.923796	12.43566	-64.018	53.12577
6.94044	11.97584	-61.027	52.83812
6.957084	11.50499	-58.03	52.5562
6.973728	11.02548	-55.0309	52.28149
6.990371	10.53957	-52.0327	52.0153
7.007015	10.04923	-49.0366	51.75871
7.023659	9.55617	-46.0422	51.51261
7.040303	9.061785	-43.0475	51.2777
7.056946	8.567504	-40.0508	51.05466
7.07359	8.074953	-37.0522	50.84426
7.090234	7.585872	-34.0523	50.64724
7.106878	7.101745	-31.0509	50.46419
7.123521	6.623943	-28.0472	50.2956
7.140165	6.153787	-25.0405	50.14192
7.156809	5.692556	-22.0303	50.00354
7.173453	5.241475	-19.016	49.88078
7.190096	4.801716	-15.9971	49.77392
7.20674	4.374402	-12.9732	49.68316
7.223384	3.960599	-9.94391	49.60865
7.240028	3.561323	-6.90899	49.55048
7.256671	3.177533	-3.8682	49.50869
7.273315	2.810133	-0.82135	49.48324
7.289959	2.459995	2.231427	49.47407
7.306602	2.134631	5.226449	49.48071
7.323246	1.828018	8.219505	49.50256
7.33989	1.540033	11.21706	49.53935
7.356534	1.271615	14.21446	49.59073
7.373177	1.023194	17.21119	49.65627
7.389821	0.795239	20.20519	49.73548
7.406465	0.587749	23.19989	49.82798
7.423109	0.40091	26.19622	49.93334
7.439752	0.234995	29.19303	50.05103
7.456396	0.090229	32.18842	50.18044
7.47304	-0.03338	35.1836	50.32107
7.489684	-0.13578	38.1786	50.47237
7.506327	-0.217	41.17389	50.63379
7.522971	-0.27706	44.16968	50.80478

7.539615	-0.31603	47.16563	50.98474
7.556259	-0.334	50.16038	51.17299
7.572902	-0.33113	53.15489	51.36899
7.589546	-0.3076	56.14898	51.57215
7.60619	-0.26364	59.1425	51.78185
7.622834	-0.19948	62.13505	51.99748
7.639477	-0.11543	65.12642	52.21842
7.656121	-0.0118	68.11625	52.44407
7.672765	0.111038	71.10417	52.67381
7.689409	0.252689	74.08979	52.90704
7.706052	0.412724	77.07277	53.14317
7.722696	0.590684	80.05279	53.38161
7.73934	0.786084	83.02958	53.6218
7.755983	0.99841	86.00289	53.86317
7.772627	1.227129	88.97251	54.10519
7.789271	1.471681	91.93826	54.34734
7.805915	1.731491	94.89999	54.58909
7.822558	2.005961	97.85759	54.82997
7.839202	2.294478	100.811	55.06948
7.855846	2.596425	103.7602	55.30718
7.87249	2.914939	106.7399	55.54538
7.889133	3.248388	109.7376	55.78258
7.905777	3.594375	112.7366	56.01696
7.922421	3.9518	115.7333	56.24781
7.939065	4.319958	118.7279	56.47471
7.955708	4.698375	121.7227	56.69741
7.972352	5.086425	124.7185	56.91554
7.988996	5.483304	127.7151	57.12869
8.00564	5.888104	130.7117	57.33637
8.022283	6.299922	133.7077	57.53816
8.038927	6.717933	136.7033	57.73368
8.055571	7.141359	139.6993	57.9226
8.072215	7.569285	142.6954	58.10452
8.088858	8.000804	145.6918	58.27908
8.105502	8.434962	148.6884	58.44592
8.122146	8.870745	151.6848	58.60464
8.13879	9.30718	154.6813	58.7549
8.155433	9.743262	157.6779	58.89635
8.172077	10.17799	160.6747	59.02867
8.188721	10.61036	163.6723	59.15152
8.205365	11.03936	166.6709	59.26458
8.222008	11.46395	169.6712	59.36752
8.238652	11.88307	172.6734	59.46002
8.255296	12.29562	175.6781	59.54175
8.271939	12.70051	178.6857	59.61238
8.288583	13.09659	-178.303	59.67159

8.305227	13.4827	-175.289	59.71905
8.321871	13.85766	-172.27	59.75444
8.338514	14.22025	-169.246	59.77743
8.355158	14.56924	-166.218	59.78771
8.371802	14.90337	-163.184	59.78497
8.388446	15.22138	-160.146	59.76892
8.405089	15.52199	-157.101	59.73927
8.421733	15.80372	-154.053	59.69581
8.438377	16.06188	-151.044	59.63921
8.455021	16.2966	-148.067	59.56975
8.471664	16.5101	-145.086	59.48663
8.488308	16.70129	-142.099	59.38973
8.504952	16.8691	-139.108	59.279
8.521596	17.01251	-136.112	59.15441
8.538239	17.13057	-133.113	59.01599
8.554883	17.22242	-130.109	58.86386
8.571527	17.28727	-127.103	58.69819
8.588171	17.32448	-124.095	58.51922
8.604814	17.33351	-121.1	58.32823
8.621458	17.31424	-118.105	58.12485
8.638102	17.26642	-115.111	57.90957
8.654746	17.18998	-112.119	57.68294
8.671389	17.08498	-109.129	57.4456
8.688033	16.95164	-106.142	57.19827
8.704677	16.79037	-103.158	56.94175
8.72132	16.60169	-100.18	56.67687
8.737964	16.38628	-97.2056	56.40455
8.754608	16.14499	-94.2372	56.12574
8.771252	15.87878	-91.2748	55.84146
8.787895	15.58876	-88.3189	55.55277
8.804539	15.27612	-85.3698	55.26073
8.821183	14.94218	-82.4277	54.96642
8.837827	14.58812	-79.4911	54.67079
8.85447	14.20838	-76.5066	54.36952
8.871114	13.80751	-73.5036	54.06671
8.887758	13.39028	-70.5071	53.76606
8.904402	12.9581	-67.5147	53.46851
8.921045	12.51149	-64.5185	53.17443
8.937689	12.05258	-61.5214	52.88526
8.954333	11.58338	-58.525	52.60228
8.970977	11.10565	-55.5292	52.32657
8.98762	10.62109	-52.5334	52.05911
9.004264	10.1313	-49.5365	51.80082
9.020908	9.638147	-46.5392	51.5527
9.037552	9.14344	-43.542	51.31568
9.054195	8.648848	-40.5446	51.09055

9.070839	8.155987	-37.5468	50.87806
9.087483	7.666381	-34.5481	50.67885
9.104127	7.181479	-31.5479	50.4935
9.12077	6.702669	-28.5454	50.32253
9.137414	6.231286	-25.5401	50.16639
9.154058	5.768614	-22.5313	50.02549
9.170702	5.315886	-19.5186	49.90014
9.187345	4.874283	-16.5013	49.79064
9.203989	4.444934	-13.4791	49.69721
9.220633	4.028914	-10.4516	49.61999
9.237276	3.627247	-7.41851	49.5591
9.25392	3.240899	-4.37956	49.51457
9.270564	2.870785	-1.33459	49.48639
9.287208	2.517761	1.716508	49.47448
9.303851	2.18658	4.736698	49.47857
9.320495	1.877283	7.725923	49.49792
9.337139	1.587837	10.70519	49.53203
9.353783	1.317511	13.68589	49.58063
9.370426	1.066491	16.67093	49.64342
9.38707	0.835158	19.66095	49.72008
9.403714	0.623906	22.65586	49.81021
9.420358	0.433088	25.65541	49.9134
9.437001	0.263008	28.65923	50.02919
9.453645	0.113914	31.66692	50.15708
9.470289	-0.014	34.6781	50.29657
9.486933	-0.12053	37.69035	50.447
9.503576	-0.20491	40.67366	50.60616
9.52022	-0.26832	43.65887	50.77498
9.536864	-0.31077	46.64545	50.95288
9.553508	-0.33235	49.63318	51.13927
9.570151	-0.33316	52.62164	51.33355
9.586795	-0.31335	55.61039	51.5351
9.603439	-0.27313	58.59893	51.74331
9.620083	-0.21273	61.58683	51.95755
9.636726	-0.13245	64.57366	52.17721
9.65337	-0.03259	67.559	52.40167
9.670014	0.08649	70.54248	52.63032
9.686657	0.224396	73.52371	52.86257
9.703301	0.38071	76.50238	53.09781
9.719945	0.554981	79.47816	53.33546
9.736589	0.74673	82.45077	53.57496
9.753232	0.955453	85.41996	53.81576
9.769876	1.180621	88.38551	54.0573
9.78652	1.421683	91.34724	54.29907
9.803164	1.678069	94.30498	54.54055
9.819807	1.949644	97.26345	54.78164

9.836451	2.238784	100.2519	55.02424
9.853095	2.543243	103.2502	55.2662
9.869739	2.861673	106.25	55.50638
9.886382	3.193015	109.2476	55.74399
9.903026	3.536626	112.2432	55.97862
9.91967	3.89195	115.238	56.20991
9.936314	4.258356	118.2328	56.43747
9.952957	4.635199	121.2281	56.66093
9.969601	5.02184	124.2247	56.87992
9.986245	5.417345	127.2214	57.09393
10.00289	5.820895	130.2179	57.30254
10.01953	6.231683	133.2145	57.50536
10.03618	6.648842	136.211	57.70199
10.05282	7.07152	139.2075	57.89206
10.06946	7.498817	142.2039	58.07517
10.08611	7.929815	145.2003	58.25097
10.10275	8.363595	148.1967	58.41909
10.11939	8.799211	151.1935	58.57918
10.13604	9.235715	154.1907	58.73089
10.15268	9.671996	157.1877	58.87383
10.16933	10.10708	160.1849	59.00769
10.18597	10.53997	163.1828	59.13212
10.20261	10.96966	166.1817	59.24682
10.21926	11.39511	169.1822	59.35145
10.2359	11.81527	172.1846	59.44569
10.25254	12.22905	175.1894	59.52921
10.26919	12.63533	178.1971	59.60168
10.28583	13.033	-178.792	59.66278
10.30248	13.42089	-175.777	59.71218
10.31912	13.79781	-172.758	59.74955
10.33576	14.16255	-169.735	59.77457
10.35241	14.51389	-166.707	59.78692
10.36905	14.85057	-163.674	59.7863
10.38569	15.17133	-160.635	59.77241
10.40234	15.47489	-157.591	59.74496
10.41898	15.7595	-154.546	59.70378
10.43563	16.02048	-151.543	59.64955
10.45227	16.25911	-148.561	59.58221
10.46891	16.47664	-145.575	59.50118
10.48556	16.67193	-142.583	59.40633
10.5022	16.84393	-139.586	59.2976
10.51884	16.99158	-136.584	59.17495
10.53549	17.11392	-133.579	59.03841
10.55213	17.20984	-130.578	58.8885
10.56878	17.27871	-127.586	58.72569
10.58542	17.32022	-124.597	58.54998

10.60206	17.33396	-121.607	58.36142
10.61871	17.31954	-118.616	58.16039
10.63535	17.27666	-115.625	57.94734
10.65199	17.20521	-112.635	57.72282
10.66864	17.10521	-109.647	57.48747
10.68528	16.97686	-106.661	57.24198
10.70193	16.8205	-103.679	56.98713
10.71857	16.63665	-100.7	56.72378
10.73521	16.42597	-97.7271	56.45282
10.75186	16.18928	-94.7591	56.17522
10.7685	15.92751	-91.797	55.89197
10.78514	15.64175	-88.8414	55.60413
10.80179	15.33319	-85.8926	55.31274
10.81843	15.0031	-82.9506	55.0189
10.83508	14.65037	-79.9956	54.72166
10.85172	14.27273	-77.0019	54.41952
10.86836	13.87474	-73.9981	54.11649
10.88501	13.45955	-70.9966	53.81502
10.90165	13.02938	-68.0014	53.51668
10.91829	12.58586	-65.0115	53.2225
10.93494	12.12946	-62.0185	52.93282
10.95158	11.6612	-59.0179	52.64837
10.96823	11.184	-56.0173	52.37096
10.98487	10.70008	-53.0193	52.10189
11.00151	10.21132	-50.0244	51.84221
11.01816	9.719348	-47.0318	51.59274
11.0348	9.225189	-44.0371	51.35403
11.05144	8.730431	-41.0395	51.12687
11.06809	8.236883	-38.04	50.91212
11.08473	7.746284	-35.0393	50.71054
11.10138	7.260152	-32.0371	50.52275
11.11802	6.779902	-29.0328	50.34928
11.13466	6.306878	-26.0258	50.1906
11.15131	5.842374	-23.0154	50.0471
11.16795	5.387634	-20.0011	49.91915
11.18459	4.943849	-16.9823	49.80702
11.20124	4.512159	-13.9587	49.71095
11.21788	4.093652	-10.9298	49.6311
11.23453	3.68936	-7.8954	49.56758
11.25117	3.300262	-4.85514	49.52045
11.26781	2.927281	-1.80886	49.4897
11.28446	2.571441	1.242186	49.47527
11.3011	2.239852	4.239246	49.47682
11.31774	1.927126	7.231725	49.49368
11.33439	1.632824	10.22896	49.5256
11.35103	1.35796	13.22584	49.5722

11.36768	1.102932	16.22245	49.6331
11.38432	0.868144	19.21804	49.70787
11.40096	0.653829	22.21323	49.79607
11.41761	0.460155	25.20913	49.89725
11.43425	0.287381	28.20483	50.01089
11.45089	0.135631	31.20069	50.1365
11.46754	0.005022	34.19643	50.27351
11.48418	-0.10437	37.19153	50.42136
11.50083	-0.19257	40.18654	50.5795
11.51747	-0.2596	43.18224	50.74741
11.53411	-0.30551	46.17822	50.92448
11.55076	-0.33039	49.17395	51.1101
11.5674	-0.33436	52.16942	51.30367
11.58404	-0.31761	55.16431	51.50458
11.60069	-0.28033	58.1588	51.71225
11.61733	-0.22275	61.15268	51.92607
11.63398	-0.14517	64.14531	52.1454
11.65062	-0.04791	67.13628	52.36961
11.66726	0.068687	70.12517	52.5981
11.68391	0.204221	73.11164	52.83026
11.70055	0.358284	76.09556	53.06551
11.71719	0.530426	79.07664	53.30326
11.73384	0.720172	82.05462	53.54294
11.75048	0.927018	85.0292	53.784
11.76713	1.150434	88.00015	54.02587
11.78377	1.389871	90.96729	54.26804
11.80041	1.644757	93.93045	54.50999
11.81706	1.914501	96.88951	54.75121
11.8337	2.198496	99.84437	54.99123
11.85034	2.496119	102.795	55.22958
11.86699	2.807571	105.7491	55.46643
11.88363	3.136472	108.7441	55.70427
11.90028	3.479357	111.7511	55.94029
11.91692	3.833713	114.7537	56.17274
11.93356	4.198799	117.7519	56.4012
11.95021	4.573874	120.746	56.62526
11.96685	4.958176	123.7361	56.84455
11.98349	5.351521	126.727	57.05899
12.00014	5.753407	129.7207	57.26832
12.01678	6.163373	132.7196	57.47228
12.03343	6.579894	135.7186	57.67012
12.05007	7.001819	138.7158	57.86133
12.06671	7.428211	141.7107	58.04553
12.08336	7.858299	144.7046	58.22241
12.1	8.29131	147.6985	58.39168

TABLE AA.1: *Angular Displacement of Lever, Driving Disc, Main Coupler*

APPENDIX II

θ	α	θ disp	α disp
-87.3535	130.8734	2.61459	0.912453
-84.1502	130.7001	5.817926	0.739184
-80.936	130.5438	9.032098	0.582925
-77.7124	130.4052	12.25565	0.444288
-74.481	130.2847	15.48706	0.323803
-71.2434	130.1828	18.72473	0.221913
-68.001	130.0999	21.96707	0.138971
-64.7556	130.0361	25.21247	0.075234
-61.5088	129.9918	28.45935	0.030867
-58.262	129.9668	31.70615	0.005941
-55.0167	129.9613	34.95139	0.000436
-51.7744	129.9751	38.19368	0.014246
-48.5364	130.0081	41.43169	0.047184
-45.2941	130.0601	44.67396	0.099171
-41.9856	130.1325	47.9825	0.171607
-38.6828	130.2241	51.28532	0.263178
-35.3867	130.3343	54.58135	0.373431
-32.0957	130.4629	57.87236	0.501963
-28.805	130.6094	61.16311	0.648516
-25.5165	130.7734	64.45164	0.812543
-22.2344	130.9542	67.73365	0.993282
-18.9606	131.1509	71.00747	1.190012
-15.6947	131.363	74.27337	1.402084
-12.437	131.5897	77.53113	1.628788
-9.18809	131.8302	80.78001	1.869345
-5.95008	132.0837	84.01802	2.12284
-2.7241	132.3493	87.244	2.388371
0.489488	132.626	90.45759	2.665071
3.690581	132.913	93.65868	2.952076
6.879297	133.2094	96.8474	3.248526
10.05575	133.5144	100.0239	3.553548
13.22012	133.8272	103.1882	3.866267
16.37266	134.1467	106.3408	4.1858
19.51356	134.4722	109.4817	4.511256
22.64306	134.8026	112.6112	4.841737
25.76136	135.1372	115.7295	5.176333
28.86868	135.475	118.8368	5.514133
31.96521	135.8151	121.9333	5.854216
35.05117	136.1566	125.0193	6.195659
38.12675	136.4984	128.0949	6.537536
41.19213	136.8398	131.1602	6.878918
44.24506	137.1795	134.2132	7.218606

47.2289	137.5103	137.197	7.549398
50.18698	137.8362	140.1551	7.875263
53.13254	138.1577	143.1006	8.19682
56.06836	138.4744	146.0365	8.513527
58.99517	138.7855	148.9633	8.82463
61.91198	139.0901	151.8801	9.129203
64.8133	139.3868	154.7814	9.425897
67.6899	139.674	157.658	9.713072
70.55507	139.9523	160.5232	9.991378
73.41101	140.2212	163.3791	10.26033
76.25886	140.4803	166.227	10.51935
79.09885	140.7287	169.067	10.76781
81.9312	140.966	171.8993	11.00507
84.75597	141.1915	174.7241	11.23056
87.57233	141.4045	177.5404	11.44364
90.37988	141.6047	180.348	11.64378
93.1728	141.791	183.1409	11.83014
95.95851	141.9637	185.9266	12.00282
98.7373	142.1223	188.7054	12.16144
101.5093	142.2665	191.4774	12.30564
104.2747	142.396	194.2428	12.43512
107.0339	142.5105	197.002	12.54962
109.7873	142.6098	199.7554	12.64893
112.535	142.6937	202.5031	12.73284
115.2773	142.7621	205.2454	12.80122
118.0145	142.8149	207.9826	12.85397
120.7469	142.8519	210.715	12.89101
123.4748	142.8732	213.4429	12.91234
126.1985	142.8788	216.1666	12.91795
128.9184	142.8688	218.8865	12.9079
131.6349	142.8432	221.603	12.88227
134.3483	142.8021	224.3164	12.84118
137.059	142.7457	227.0271	12.78479
139.8092	142.6729	229.7773	12.71205
142.576	142.5842	232.5441	12.62329
145.3413	142.4801	235.3094	12.51921
148.1057	142.361	238.0738	12.4001
150.8697	142.2272	240.8378	12.26627
153.6339	142.0789	243.602	12.11805
156.4028	141.9165	246.3709	11.95557
159.182	141.7397	249.1501	11.77885
161.9677	141.5493	251.9358	11.58845
164.7597	141.3457	254.7278	11.38484
167.5576	141.1294	257.5257	11.16851
170.3613	140.9009	260.3294	10.93998
173.1713	140.6607	263.1394	10.69975
175.9889	140.4092	265.957	10.44827

178.8144	140.147	268.7825	10.18612
181.6482	139.8748	271.6163	9.913885
184.4904	139.5931	274.4585	9.632193
187.3413	139.3026	277.3094	9.341716
190.2013	139.004	280.1694	9.043114
193.071	138.698	283.0391	8.737057
195.9514	138.3851	285.9195	8.424225
198.843	138.0662	288.8111	8.105324
201.7467	137.742	291.7148	7.781078
204.6632	137.4131	294.6313	7.452239
207.5934	137.0805	297.5615	7.119573
210.538	136.7448	300.5061	6.783877
213.4977	136.4069	303.4658	6.445974
216.4734	136.0676	306.4415	6.106714
219.4656	135.7279	309.4337	5.766974
222.4751	135.3886	312.4432	5.427659
225.5025	135.0506	315.4706	5.089703
228.5483	134.715	318.5164	4.754064
231.613	134.3826	321.5811	4.42173
234.697	134.0546	324.6651	4.093712
237.7712	133.735	327.7393	3.774079
240.8245	133.4256	330.7926	3.464745
243.886	133.1245	333.8541	3.163583
246.9636	132.8317	336.9317	2.870758
250.0592	132.548	340.0273	2.587058
253.1731	132.2743	343.1412	2.313429
256.3051	132.0118	346.2732	2.050859
259.4546	131.7612	349.4227	1.800324
262.6207	131.5237	352.5888	1.562809
265.7909	131.3009	355.759	1.340029
268.9664	131.0935	358.9345	1.132561
-87.8495	130.9017	2.11858	0.94082
-84.6543	130.7262	5.313821	0.765301
-81.4483	130.5675	8.519776	0.606635
-78.2328	130.4263	11.73525	0.46543
-75.0093	130.3031	14.95879	0.342222
-71.7793	130.1984	18.18883	0.237467
-68.5443	130.1124	21.42379	0.151529
-65.3059	130.0456	24.66215	0.084679
-62.0658	129.998	27.90225	0.037098
-58.8256	129.9698	31.14253	0.008873
-55.5866	129.9609	34.38151	1.05E-07
-52.3503	129.9713	37.61779	0.010388
-49.118	130.0008	40.8501	0.039865
-45.8335	130.0501	44.13462	0.089213
-42.5316	130.1192	47.43652	0.158315
-39.235	130.2074	50.73305	0.24654

-35.9399	130.3145	54.02818	0.353625
-32.6432	130.4402	57.32486	0.479318
-29.3498	130.5839	60.61826	0.623024
-26.0621	130.745	63.90596	0.78413
-22.7804	130.923	67.18768	0.962056
-19.5052	131.1171	70.46292	1.156173
-16.2363	131.3268	73.73183	1.36585
-12.9757	131.5512	76.99238	1.590278
-9.72568	131.7895	80.24242	1.828569
-6.48658	132.0408	83.48152	2.079918
-3.25878	132.3044	86.70932	2.343494
-0.04278	132.5793	89.92532	2.61843
3.161164	132.8648	93.12926	2.903856
6.352814	133.1598	96.32091	3.198885
9.532214	133.4635	99.50031	3.502641
12.69952	133.7751	102.6676	3.814244
15.85489	134.0937	105.823	4.132808
18.99858	134.4183	108.9667	4.457445
22.13082	134.7482	112.0989	4.787256
25.25183	135.0822	115.2199	5.121336
28.36182	135.4197	118.3299	5.458771
31.46098	135.7595	121.4291	5.798641
34.54953	136.1009	124.5176	6.140023
37.62766	136.4429	127.5958	6.48199
40.69556	136.7845	130.6637	6.823612
43.75084	137.1246	133.7189	7.163676
46.73449	137.4556	136.7026	7.494708
49.69541	137.7822	139.6635	7.821292
52.64455	138.1047	142.6126	8.143787
55.58377	138.4224	145.5519	8.461549
58.51389	138.7347	148.482	8.773827
61.42918	139.0401	151.3973	9.079203
64.32911	139.3378	154.2972	9.376853
67.21316	139.6269	157.1813	9.665993
70.08755	139.9074	160.0556	9.946526
72.95247	140.1787	162.9206	10.21775
75.80111	140.4393	165.7692	10.47837
78.64122	140.6894	168.6093	10.72847
81.47304	140.9283	171.4411	10.96743
84.29514	141.1555	174.2632	11.19456
87.10853	141.3703	177.0766	11.40938
89.91333	141.5723	179.8814	11.6114
92.70934	141.761	182.6774	11.80012
95.49807	141.9361	185.4662	11.97521
98.27971	142.0972	188.2478	12.13627
101.0547	142.2439	191.0228	12.28297
103.8233	142.3759	193.7914	12.41498

106.5858	142.4929	196.5539	12.53204
109.3423	142.5948	199.3104	12.6339
112.093	142.6813	202.0611	12.72038
114.8384	142.7522	204.8065	12.79132
117.5785	142.8075	207.5466	12.84661
120.3138	142.8471	210.2819	12.88619
123.0445	142.8709	213.0126	12.91001
125.771	142.879	215.7391	12.9181
128.4936	142.8714	218.4617	12.9105
131.2127	142.8482	221.1808	12.88727
133.9287	142.8094	223.8968	12.84854
136.642	142.7554	226.6101	12.79445
139.3539	142.6861	229.322	12.72516
142.1012	142.6005	232.0693	12.63962
144.8696	142.4989	234.8377	12.53804
147.6416	142.382	237.6097	12.42114
150.4131	142.2503	240.3812	12.28938
153.1845	142.104	243.1526	12.14311
155.9567	141.9436	245.9248	11.98268
158.7306	141.7694	248.6987	11.80846
161.5077	141.5817	251.4758	11.62078
164.2975	141.3803	254.2656	11.41941
167.097	141.1658	257.0651	11.20494
169.9015	140.9391	259.8696	10.97824
172.7114	140.7007	262.6795	10.73981
175.5273	140.4511	265.4954	10.49017
178.3506	140.1907	268.3187	10.22981
181.1822	139.9202	271.1503	9.959266
184.0226	139.64	273.9907	9.679117
186.8725	139.3509	276.8406	9.389988
189.732	139.0535	279.7001	9.092563
192.6012	138.7485	282.5693	8.787573
195.4807	138.4366	285.4488	8.475696
198.3714	138.1185	288.3395	8.157629
201.2741	137.795	291.2422	7.834092
204.1895	137.4667	294.1576	7.505828
207.1185	137.1345	297.0866	7.173607
210.0618	136.7991	300.0299	6.838224
213.0201	136.4614	302.9882	6.500497
215.9942	136.1222	305.9623	6.161273
218.9849	135.7823	308.953	5.821427
221.9926	135.4428	311.9607	5.481859
225.0182	135.1044	314.9863	5.143498
228.0621	134.7682	318.0302	4.807303
231.1249	134.4352	321.093	4.474255
234.207	134.1063	324.1751	4.145364
234.7626	134.0477	324.7307	4.086812

237.2688	133.7867	327.2369	3.825777
240.3185	133.4763	330.2866	3.515416
243.3795	133.1737	333.3476	3.212753
246.4575	132.8791	336.4256	2.918196
249.5538	132.5935	339.5219	2.6326
252.6686	132.3178	342.6367	2.356927
255.8017	132.0531	345.7698	2.092177
258.9468	131.8007	348.9149	1.839774
262.0995	131.5618	352.0676	1.600896
265.2606	131.3371	355.2287	1.376224
268.4351	131.1271	358.4032	1.166155
-88.3771	130.9323	1.591001	0.971441
-85.177	130.7537	4.791056	0.792841
-81.9662	130.592	8.001932	0.631064
-78.7455	130.4476	11.22262	0.486724
-75.5164	130.3213	14.45168	0.360375
-72.2806	130.2134	17.68751	0.252489
-69.0396	130.1243	20.92854	0.163447
-65.795	130.0544	24.17314	0.093539
-62.5484	130.0039	27.41974	0.042958
-59.3013	129.9727	30.66683	0.011804
-56.0553	129.961	33.91284	8.92E-05
-52.8118	129.9686	37.15632	0.007734
-49.5722	129.9955	40.39593	0.034576
-46.3377	130.0413	43.63044	0.080376
-43.0833	130.1063	46.88481	0.14542
-39.7804	130.1915	50.18772	0.230631
-36.4702	130.296	53.49792	0.335131
-33.1697	130.4189	56.79836	0.458015
-29.8797	130.5596	60.08835	0.598695
-26.599	130.7175	63.36911	0.756637
-23.3218	130.8924	66.64629	0.931547
-20.047	131.0838	69.92107	1.122941
-16.7749	131.2911	73.19319	1.330229
-13.5097	131.5134	76.4584	1.552503
-10.255	131.7497	79.7131	1.788793
-7.01299	131.9991	82.95511	2.038155
-3.78374	132.2607	86.18436	2.299765
-0.56714	132.5337	89.40096	2.572793
2.636878	132.8173	92.60498	2.856393
5.828437	133.1106	95.79654	3.149712
9.007686	133.4128	98.97579	3.451883
12.17484	133.7229	102.1429	3.762039
15.3301	134.0402	105.2982	4.079298
18.47368	134.3637	108.4418	4.402772
21.60579	134.6925	111.5739	4.731566
24.72663	135.0257	114.6947	5.064774

27.83643	135.3624	117.8045	5.401486
30.93539	135.7017	120.9035	5.740787
34.02371	136.0427	123.9918	6.081754
37.1016	136.3844	127.0697	6.423464
40.16923	136.7259	130.1373	6.764988
43.2268	137.0663	133.1949	7.1054
46.24756	137.4017	136.2157	7.440793
49.19646	137.7273	139.1646	7.766431
52.13613	138.0493	142.1042	8.088428
55.06689	138.3669	145.035	8.405971
57.98886	138.6791	147.957	8.718241
60.90221	138.9853	150.8703	9.024435
63.80703	139.2847	153.7751	9.323755
66.70341	139.5763	156.6715	9.615425
69.59149	139.8596	159.5596	9.898691
72.47135	140.1337	162.4395	10.17282
75.33709	140.3975	165.3052	10.43657
78.17885	140.6493	168.1469	10.68844
81.00658	140.8897	170.9747	10.92881
83.8251	141.1184	173.7932	11.15752
86.63592	141.335	176.604	11.37413
89.43927	141.539	179.4074	11.57813
92.23523	141.7299	182.2033	11.76903
95.02417	141.9073	184.9923	11.9464
97.80631	142.0707	187.7744	12.10984
100.5819	142.2199	190.55	12.25898
103.351	142.3544	193.3191	12.39349
106.1138	142.474	196.0819	12.51309
108.8707	142.5784	198.8388	12.61755
111.6219	142.6676	201.59	12.70665
114.3675	142.7411	204.3356	12.78025
117.1079	142.7991	207.076	12.83822
119.8434	142.8414	209.8115	12.8805
122.5743	142.8679	212.5424	12.90703
125.3008	142.8787	215.2689	12.91783
128.0235	142.8738	217.9916	12.91293
130.7426	142.8533	220.7107	12.8924
133.4585	142.8173	223.4266	12.85635
136.1716	142.7658	226.1397	12.80493
138.8919	142.6989	228.86	12.73804
141.648	142.6157	231.6161	12.65479
144.412	142.5168	234.3801	12.55588
147.1795	142.4026	237.1476	12.44167
149.9485	142.2734	239.9166	12.31249
152.7177	142.1296	242.6858	12.16875
155.4882	141.9717	245.4563	12.01077
158.2628	141.7997	248.2309	11.83878

161.0484	141.6136	251.0165	11.65272
163.8408	141.4141	253.8089	11.45324
166.6378	141.2019	256.6059	11.24095
169.4387	140.9773	259.4068	11.01645
172.2446	140.7411	262.2127	10.78017
175.0575	140.4934	265.0256	10.53254
177.8815	140.2346	267.8496	10.27374
180.7143	139.9655	270.6824	10.00459
183.5551	139.6867	273.5232	9.725796
186.404	139.3989	276.3721	9.438045
189.2615	139.1029	279.2296	9.141972
192.1286	138.7991	282.0967	8.838231
195.0058	138.4884	284.9739	8.527491
197.8942	138.1713	287.8623	8.210444
200.7944	137.8487	290.7625	7.887808
203.7072	137.5212	293.6753	7.560323
206.6334	137.1897	296.6015	7.228754
209.5738	136.8548	299.5419	6.893889
212.5292	136.5174	302.4973	6.556545
215.5002	136.1785	305.4683	6.217563
218.4875	135.8387	308.4556	5.877811
221.492	135.4991	311.4601	5.538187
224.5141	135.1605	314.4822	5.199613
227.5544	134.8239	317.5225	4.863043
230.6136	134.4904	320.5817	4.529454
233.6919	134.1608	323.66	4.199851
236.7617	133.8391	326.7298	3.87817
239.8171	133.5268	329.7852	3.565858
242.8814	133.2223	332.8495	3.26136
245.9619	132.9258	335.93	2.964924
249.0585	132.6384	339.0266	2.677531
252.1682	132.3613	342.1363	2.400397
255.2915	132.0953	345.2596	2.134401
258.427	131.8414	348.3951	1.880534
261.5757	131.6005	351.5438	1.639574
264.7382	131.3732	354.7063	1.4123
267.9138	131.1605	357.8819	1.199557
-88.8981	130.963	1.069986	1.002131
-85.6981	130.7816	4.270017	0.82075
-82.487	130.617	7.481069	0.656104
-79.2663	130.4697	10.70177	0.508835
-76.0374	130.3404	13.93073	0.379503
-72.8018	130.2295	17.16626	0.268591
-69.5609	130.1374	20.4072	0.176478
-66.3161	130.0644	23.65199	0.103465
-63.069	130.0107	26.8991	0.049762
-59.8212	129.9764	30.14689	0.015485

-56.5743	129.9616	33.39381	0.000659
-53.3297	129.9661	36.63843	0.005219
-50.0887	129.9899	39.8794	0.029015
-46.8526	130.0327	43.11545	0.07182
-43.6216	130.0943	46.34649	0.133357
-40.3284	130.1761	49.63969	0.215166
-37.0177	130.2774	52.95036	0.31654
-33.7167	130.3973	56.25143	0.436377
-30.4258	130.535	59.54225	0.574105
-27.1438	130.6901	62.8243	0.729207
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-20.5862	131.0512	69.38193	1.090311
-17.3124	131.256	72.65571	1.295102
-14.048	131.4757	75.92007	1.514821
-10.7953	131.7095	79.17279	1.748575
-7.5548	131.9564	82.4133	1.995538
-4.32516	132.2159	85.64294	2.255011
-1.10551	132.4872	88.86259	2.52626
2.103551	132.7693	92.07165	2.808411
5.300423	133.0614	95.26852	3.100471
8.484895	133.3624	98.45299	3.401542
11.6572	133.6717	101.6253	3.710757
14.81756	133.9881	104.7857	4.027234
17.96617	134.311	107.9343	4.350085
21.10325	134.6393	111.0714	4.67841
24.22902	134.9722	114.1971	5.011306
27.34368	135.3088	117.3118	5.347858
30.44744	135.6481	120.4155	5.68715
33.54052	135.9892	123.5086	6.028258
36.62311	136.3312	126.5912	6.370255
39.6954	136.6731	129.6635	6.712212
42.75736	137.0141	132.7255	7.053173
45.74574	137.3461	135.7138	7.385179
48.71695	137.6745	138.685	7.713637
51.67771	137.9993	141.6458	8.038422
54.62374	138.3191	144.5918	8.358213
57.55492	138.6331	147.523	8.672172
60.46971	138.9402	150.4378	8.979337
63.37191	139.2402	153.34	9.279332
66.26288	139.5324	156.231	9.571532
69.142	139.816	159.1101	9.855134
72.00799	140.0902	161.9761	10.12931
74.86253	140.3544	164.8306	10.39355
77.70623	140.6082	167.6743	10.64725
80.5401	140.8508	170.5082	10.8899
83.3649	141.0818	173.333	11.12095
86.18089	141.3008	176.149	11.33987

88.98739	141.507	178.9555	11.54609
91.7859	141.7001	181.754	11.73922
94.57683	141.8798	184.5449	11.91885
97.36065	142.0455	187.3287	12.08459
100.1376	142.197	190.1057	12.23606
102.908	142.3338	192.8761	12.37295
105.6722	142.4559	195.6403	12.49497
108.4304	142.5628	198.3985	12.60187
111.1827	142.6544	201.1508	12.69345
113.9296	142.7304	203.8977	12.76955
116.6712	142.7909	206.6393	12.83003
119.4078	142.8357	209.3759	12.87481
122.1397	142.8648	212.1078	12.90386
124.8673	142.8781	214.8354	12.91716
127.5909	142.8757	217.559	12.91475
130.3109	142.8576	220.279	12.8967
133.0276	142.824	222.9957	12.86311
135.7415	142.775	225.7096	12.8141
138.453	142.7108	228.4211	12.74986
141.1945	142.6304	231.1626	12.66955
143.955	142.5342	233.9231	12.57329
146.7196	142.4226	236.6877	12.46169
149.4855	142.296	239.4536	12.33511
152.2532	142.1548	242.2213	12.19385
155.0253	141.999	244.9934	12.03813
157.803	141.8291	247.7711	11.86822
160.5864	141.6454	250.5545	11.68448
163.3753	141.4483	253.3434	11.48737
166.1695	141.2382	256.1376	11.27734
168.9696	141.0157	258.9377	11.05485
171.7767	140.7812	261.7448	10.82034
174.5909	140.5352	264.559	10.57434
177.4127	140.2783	267.3808	10.31738
180.2425	140.011	270.2106	10.05005
183.0802	139.7339	273.0483	9.772991
185.9264	139.4477	275.8945	9.486818
188.7815	139.1531	278.7496	9.192192
191.6461	138.8507	281.6142	8.889781
194.5208	138.5412	284.4889	8.580258
197.4064	138.2252	287.3745	8.264315
200.3036	137.9036	290.2717	7.942666
203.2134	137.5769	293.1815	7.616048
206.1363	137.2461	296.1044	7.285224
209.0733	136.9119	299.0414	6.950972
212.0251	136.575	301.9932	6.614102
214.9924	136.2363	304.9605	6.275449
217.9759	135.8968	307.944	5.935877

220.9764	135.5572	310.9445	5.596277
223.9945	135.2185	313.9626	5.257568
227.0307	134.8816	316.9988	4.920695
230.0855	134.5475	320.0536	4.586632
233.1595	134.2173	323.1276	4.256377
236.2508	133.8921	326.2189	3.931189
239.3167	133.5773	329.2848	3.616432
242.3628	133.2731	332.3309	3.312248
245.4274	132.9765	335.3955	3.015627
248.5109	132.6884	338.479	2.727546
251.613	132.4099	341.5811	2.449004
254.7333	132.1419	344.7014	2.180997
257.8715	131.8854	347.8396	1.92452
261.0268	131.6414	350.9949	1.680544
264.1985	131.4109	354.1666	1.450015

TABLE II: *values of* Θ *and* α

APPENDIX III

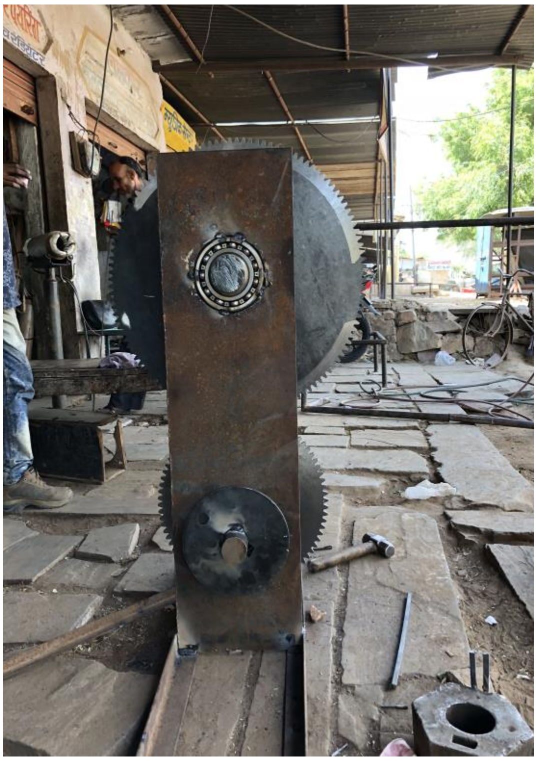


Figure III.a: Setup

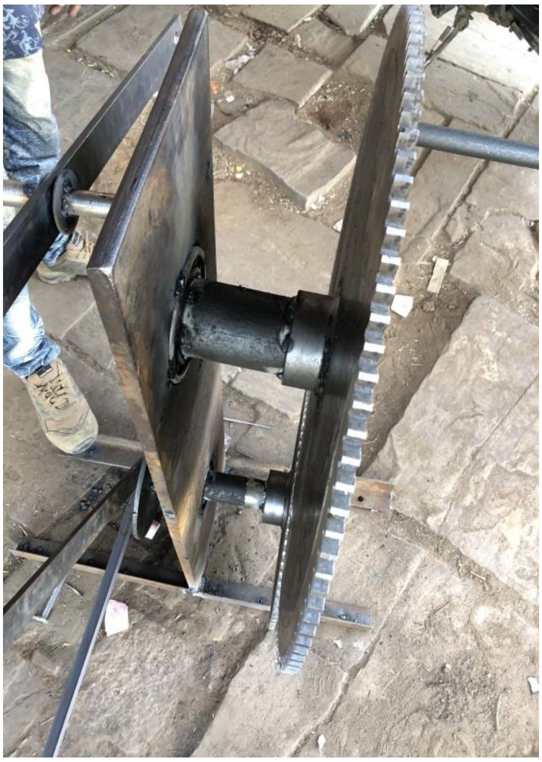
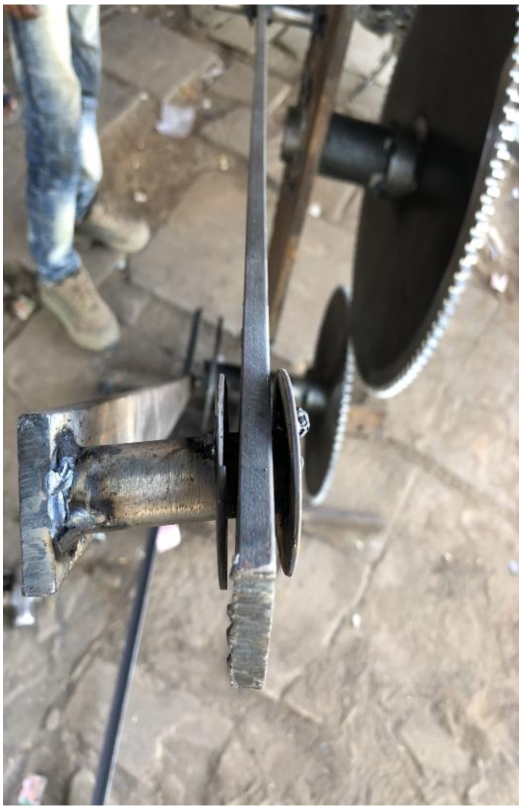


Figure III.b: Driving gear



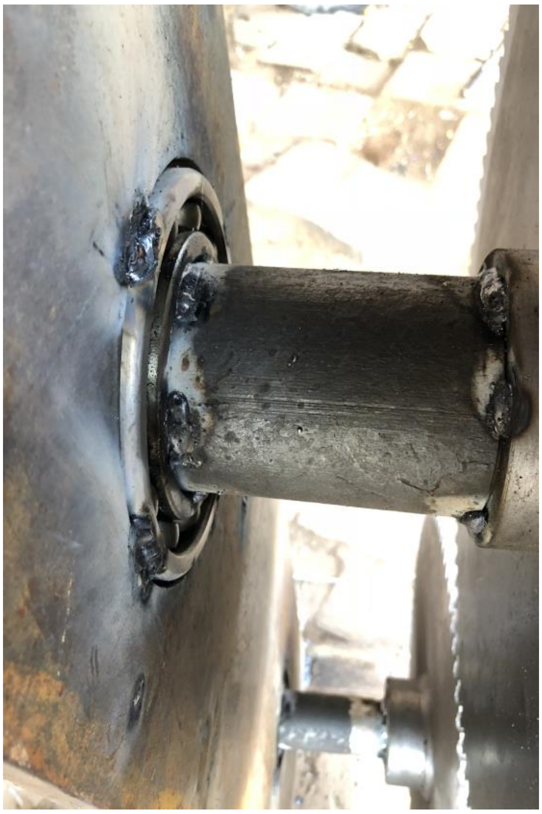
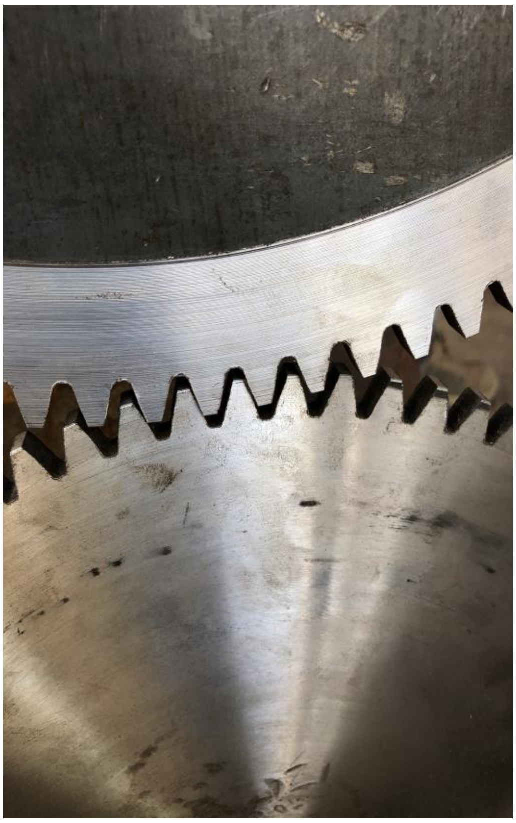


Figure III.c: Coupler-lever hinge point

Figure III.d: Shafts



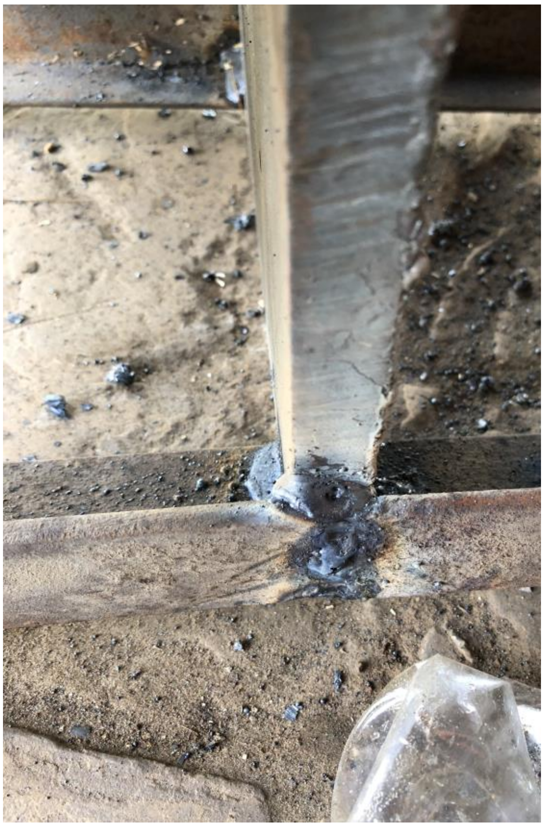


Figure III.e: Gear Meshing

Figure III.f: Angle bracket-mount weld joint

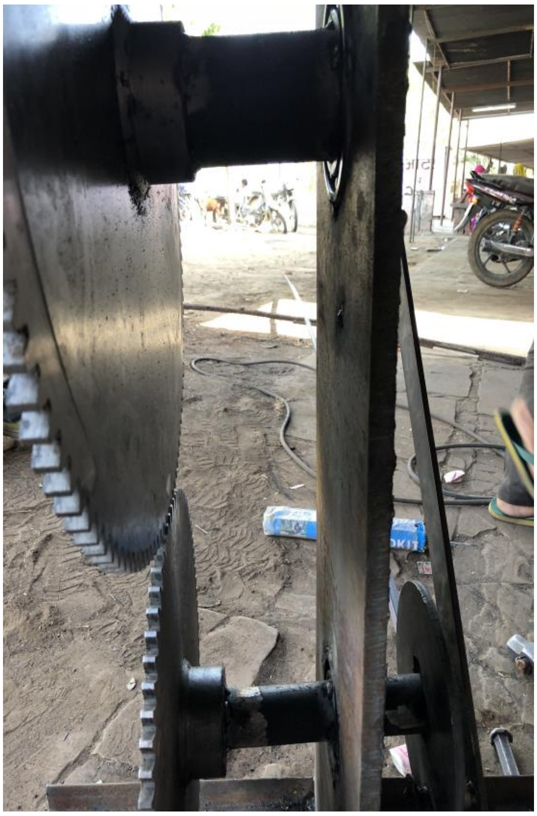


Figure III.g: Column

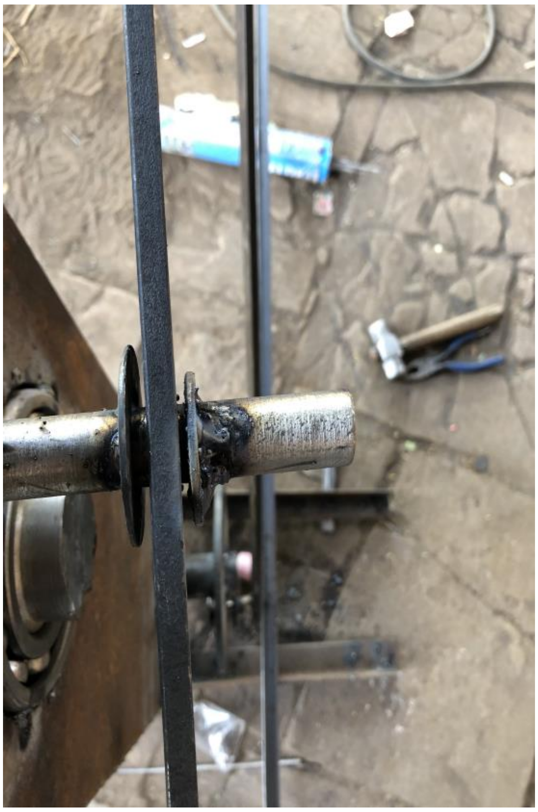


Figure III.h: Lever hinge point

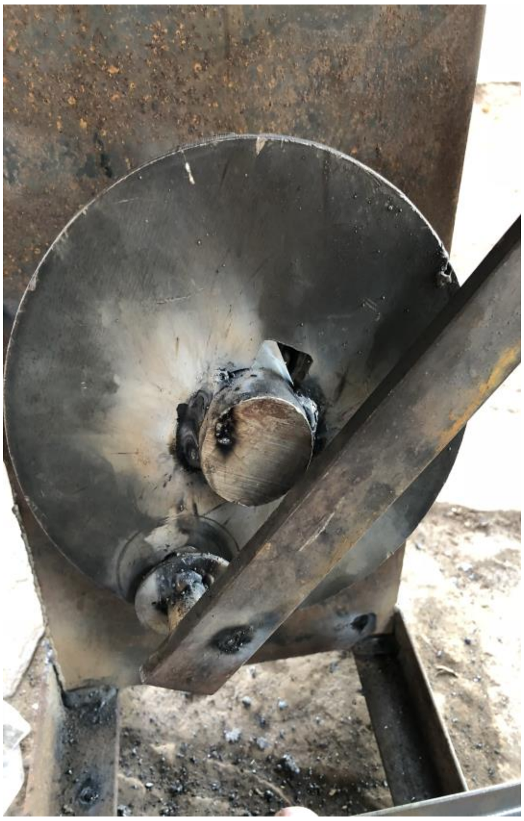


Figure III.i: Driving disc

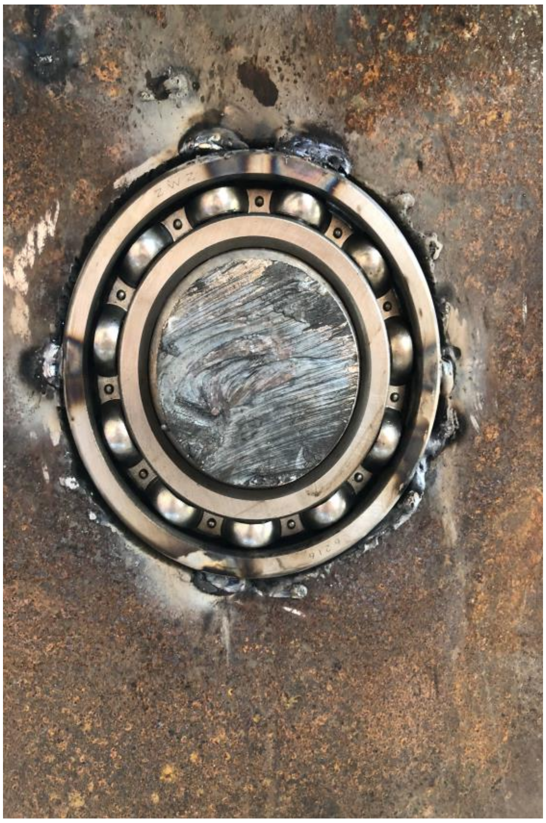


Figure III.j: Ball Bearing

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